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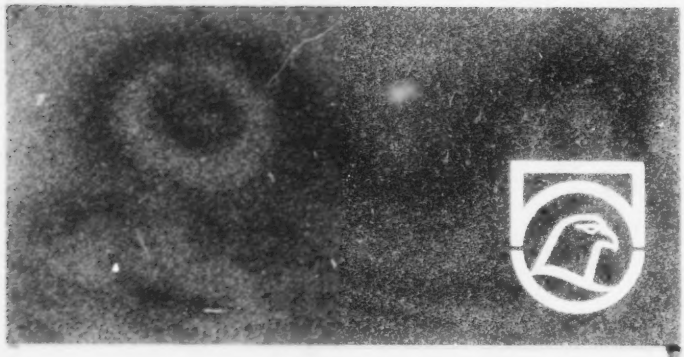

FALCONBRIDGE

REPAIR AND RECLAMATION TECHNOLOGY OF CAST IRON MINING EQUIPMENT MACHINERY

PHASE I: Technical and Economic Importance of Grey Cast Iron Repairs

Phase I, Final Report

By

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ABSTRACT

Grey iron castings serve important functions in mining, mineral processing and metallurgical operations. Applications for grey iron are illustrated with reference to flowsheets for mining operations. A general welding repair procedure is given and five case studies are used to examine the technical and cost effectiveness of grey cast iron welding repairs.

The case studies show that considerable cost savings can be achieved by welding repair. Research is required to improve the existing procedures and to examine new repair-welding processes.

RÉSUMÉ

La fonte de fer graphitée remplit des fonctions importantes dans le domaine des mines, du traitement due minerai et dans les opérations métallurgiques. Les applications de la fonte graphitée sont illustrées par des diagrammes opérationnels ayant trait aux opérations minières. Le procédé général de réparation par soudure se trouve indiqué, accompagne dé cinq exemples permettant d'étudier l'efficacité technique et le coût de réparations par soudure de la fonte graphitée.

Ces exemples démontrent qu'une économie considérable peut être réalisée grâce aux réparations par soudure.

Il faudrait donc entreprendre des recherches qui permettraient d'améliorer les procédés en existence et d'étudier de nouveaux procédés de repáration par soudure.

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1. BACKGROUND AND INTRODUCTION

This study was undertaken for CANMET, under the direction of Mr. R.D. McDonald, as part of a program to improve the existing technology for repair and reclaimation of mining equipment. This report concludes Phase I of the study, which was designed to evaluate the technical and economic importance of grey cast iron repairs. Phase II of this program is designed to improve the existing welding repair procedures and to evaluate new repair-welding processes.

There are several methods recommended for welding of grey iron castings (1 to 8). However, in repair welding of used grey iron mining equipment a number of difficulties occur, which are not normally encountered during original equipment manufacture and these include:

(1) dirt, oil and rust from service exposure

(2) non-uniform section thickness and geometry due to irregular crack progression

(3) difficulty of positioning for weld preparation and welding

(4) difficulty of preheating and cooling uniformly

Grey iron castings are used for many large components in the mining industry, such as equipment foundations, crusher jaws and bearing housings. Since the castings may weigh several tons, repair welding often must be done in-situ. Random crack propagation very rarely allows automatic welding methods to be used but in some cases, downhand or horizontal positioning may allow the use of semi-automatic welding processes such as FCAW(5) or GMAW(3). However, they are not currently used in repairing mining equipment and manual SMAW is used almost exclusively.

Random crack paths preclude the use of standard machine shop tools for weld preparation, consequently manual preparation with torches, grinders and chisels is required to produce rough "U", "V" or tulip-shaped grooves. In addition, the removal of dirt and oil from used equipment is often difficult. Speciality electrodes have been prepared for this purpose, but reliable, comparative data on their performance is lacking.

'Hot' or 'cold' welding methods can be used. Although 'hot' welding (preheat 300° to 500°C) is considered to produce stronger, more pressure-tight weldments, it is difficult to use on large castings repaired in-situ. 'Cold' welding is more applicable and acceptable results can be obtained in many cases, but there is lack of comparative data on these two methods.

This report examines the technical function of grey iron castings with reference to the flowsheets of typical mining operations. Case studies are used to examine the technical and cost effectiveness of grey cast iron welding repairs. Phase II will be a research program which addresses the problems identified above, in an attempt to improve the existing technology for repair-welding of grey iron mining equipment.

2. APPLICATIONS FOR GREY IRON IN MINING OPERATIONS

Canadian mining operations vary in size and complexity from small quarry operations to large, integrated, mining-milling-smelting-refining complexes (9,10). Applications for grey cast irons are diverse due to the variety of process operations and equipment used (9 to 13). Grey iron castings are used in both flake graphite and nodular graphite forms, at various strength levels, depending on the properties required. Grey irons are commonly specified in accordance to ASTM specifications A48-76 (14) or A536-80 (15), but proprietary grades are also popular.

Figure 1 is a flowsheet for a quarry operation producing sand products. Rock is blasted, loaded on to trucks and hauled to crushing plants at two quarry sites. Subsequent processing includes drying, screening, crushing, grinding, flotation, desliming, sizing and magnetic separation.

Figures 2 and 3 are flowsheets for parts of an integrated mining-milling-smelting operation producing nickel-copper matte. Major operations include crushing, grinding and flotation at the mill. The major operations at the smelter are roasting, smelting, converting and acid production.

Each process step shown in Figures 1 to 3 is dependent on the previous step for feed. A major failure of any machinery in the flowsheet can stop production in an entire circuit or an entire plant. Hence, rapid machinery replacement or repair must be accomplished if an unexpected failure occurs. The examples which follow show grey cast iron components that are used for the process steps shown above and they illustrate the wide use of grey irons in the Canadian mining industry.

Mining usually consists of drilling, blasting, digging and hauling operations. Diesel driven tractors such as shown in Figure 4 are commonly used to remove overburden from the ore body.

The diesel engine contains numerous grey iron components. Figure 5 is a rebuilt cylinder head from a diesel engine. Welding is used to repair cracks and worn areas by a commercial shop specializing in this type of repair (16).

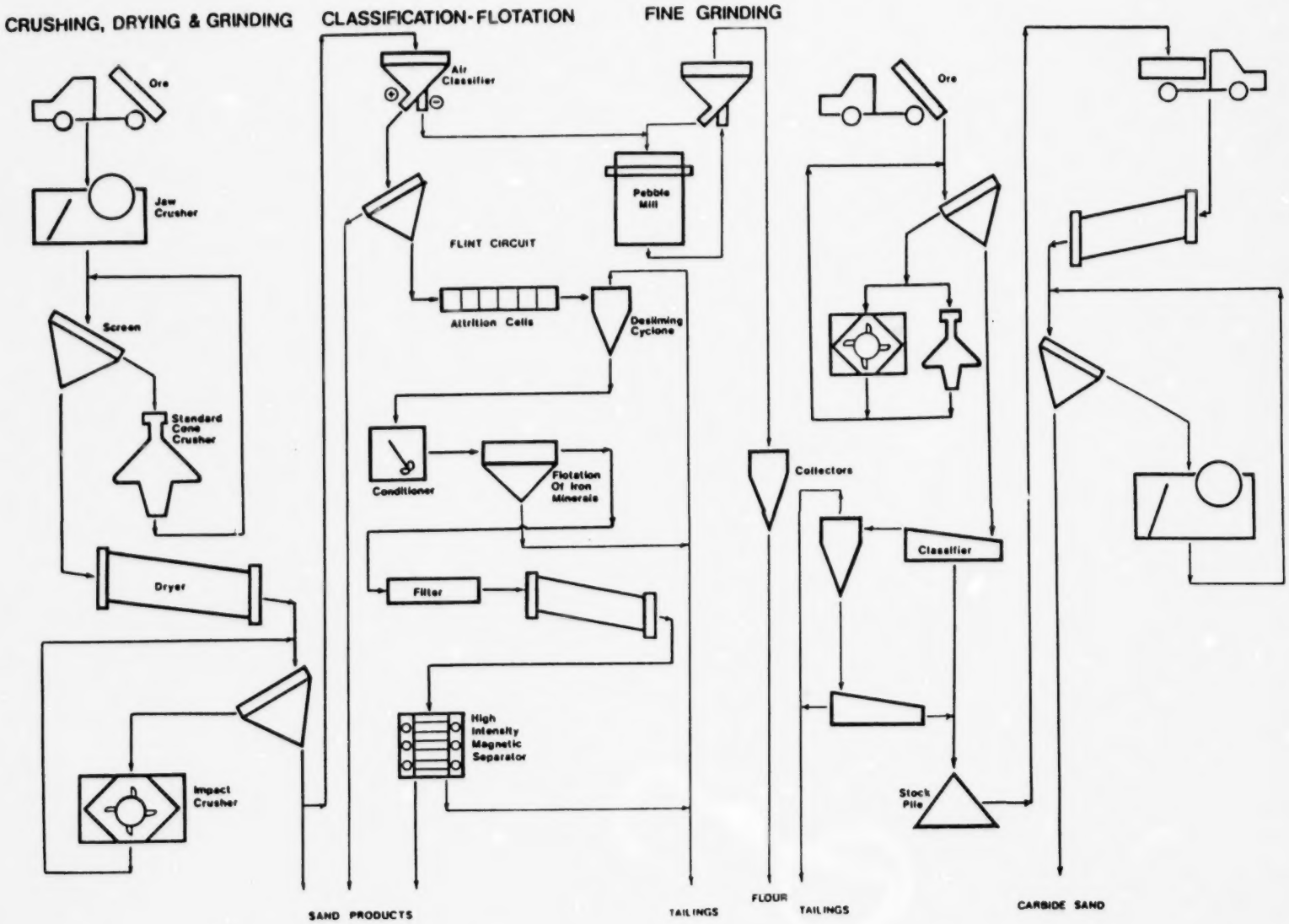


FIGURE 1: Simplified Flowsheet for Quarry Operation Producing Sand Products

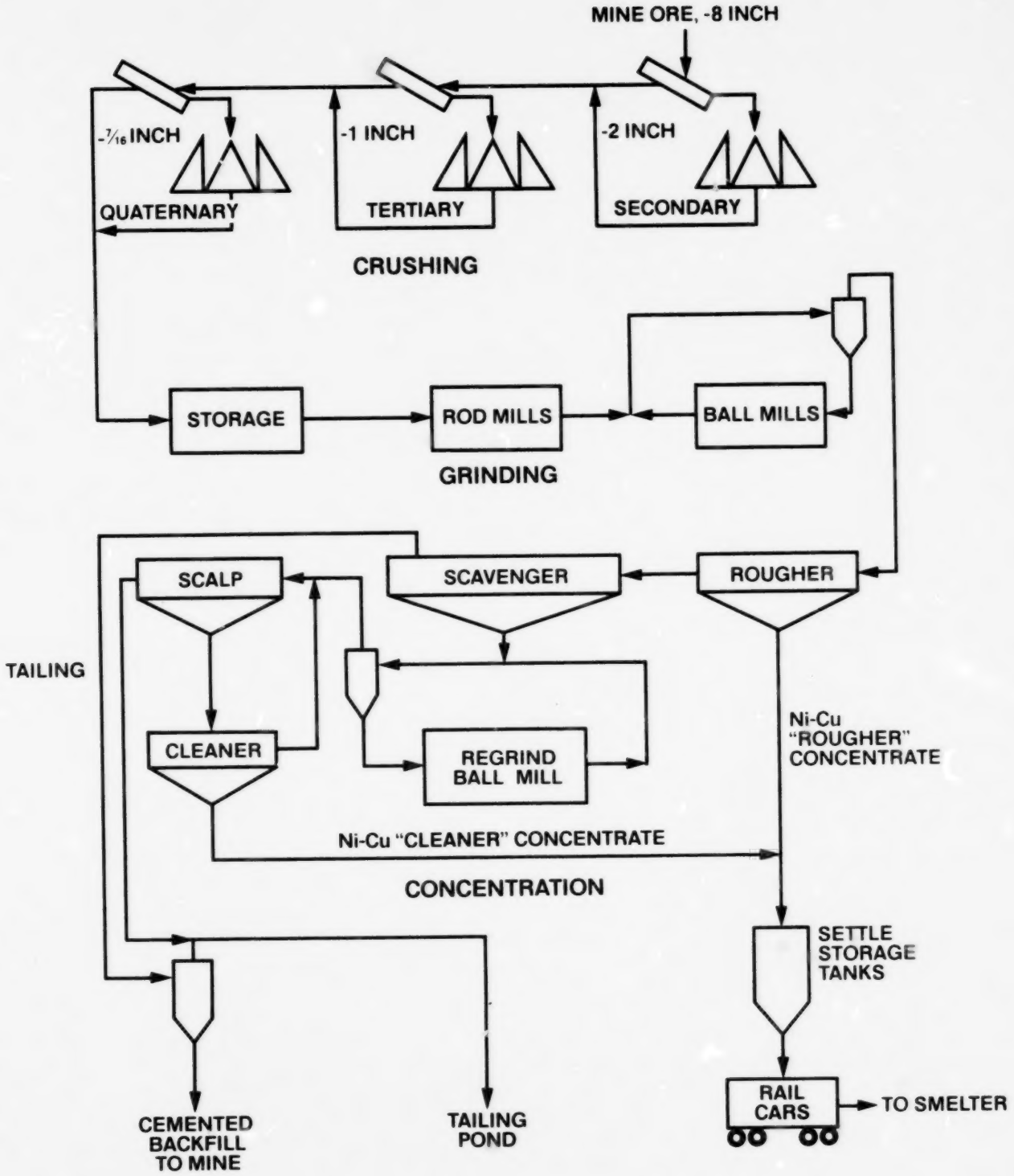


FIGURE 2: Simplified Flowsheet for Mill Producing Copper-Nickel Flotation Concentrates

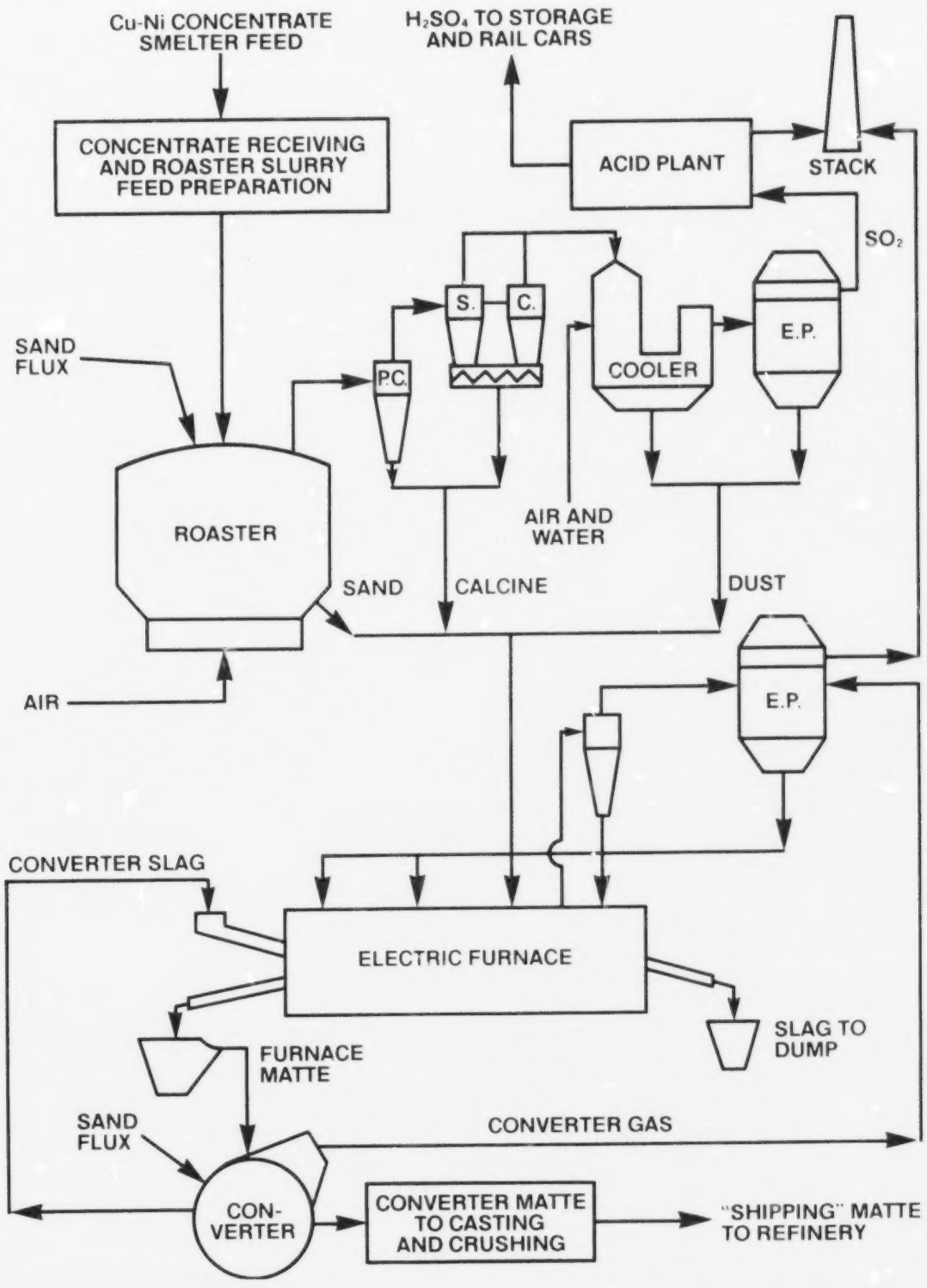


FIGURE 3: Simplified Flowsheet for Smelter Producing Nickel-Copper Matte and Sulphuric Acid

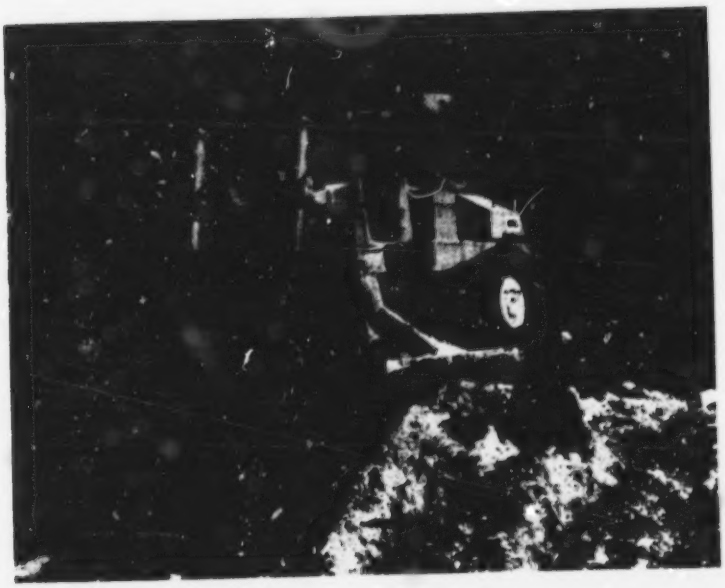


FIGURE 4: Diesel Driven Bulldozer Used to Remove Overburden at a Mine Site (21)

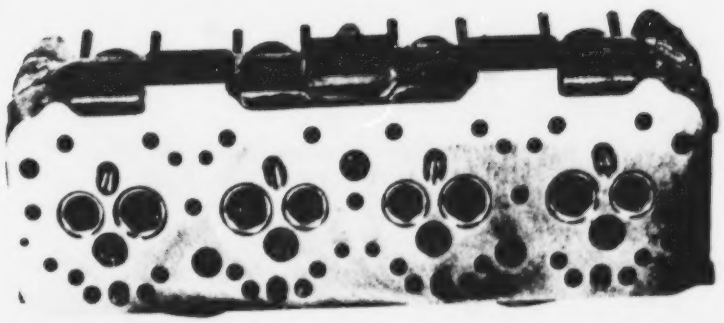


FIGURE 5: Rebuilt Cylinder Head Repaired by a Commercial Shop Specializing in Welding Repair and Refinishing of these Components (16)

Various types of equipment are used to dig the ore after drilling and blasting. Figure 6 shows a control cable drum from a power shovel and figure 7 is a much larger cable drum which has been rebuilt with a nickel base alloy, prior to machining. Both of these cable drums are made of grey iron. Cast iron brake drums are also used on a variety of mining equipment.

After being removed from the mine site, the ore is usually hauled in trucks or trains or conveyed to crushing plants. When the ore arrives at the mill, the first step in the operation may be ore drying. Figure 8 shows the cast iron drive gear and support roller on an ore drying kiln. Figure 9 is a close-up of the cast iron gears which rotate the kiln in more detail.

Ore will generally be crushed in several stages (i.e. primary, secondary and tertiary). Many jaw crusher components are made of cast iron as detailed in the case studies which follow (Sections 4.1, 4.3 and 4.5). Jaw crusher drive rolls, fly wheels, toggle plates, motor housings and speed reducer housings are often made of grey iron.

Figure 10 is a mulitiple V-belt drive with cast iron pulleys (17). These drive systems are often used for crushers. Figure 11 shows a drive roll from a roll crusher which has been repair welded.

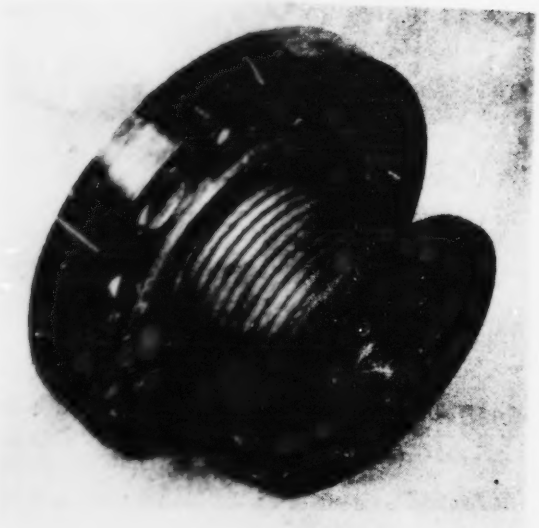


FIGURE 6: Power Shovel Control Cable Drum Made of Grey Iron (17)

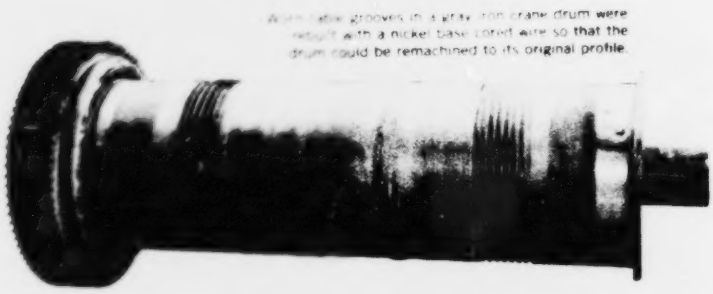


FIGURE 7: Worn Cable Grooves in a Grey Iron Cable Drum which were Rebuilt With a Nickel Alloy Wire (1)

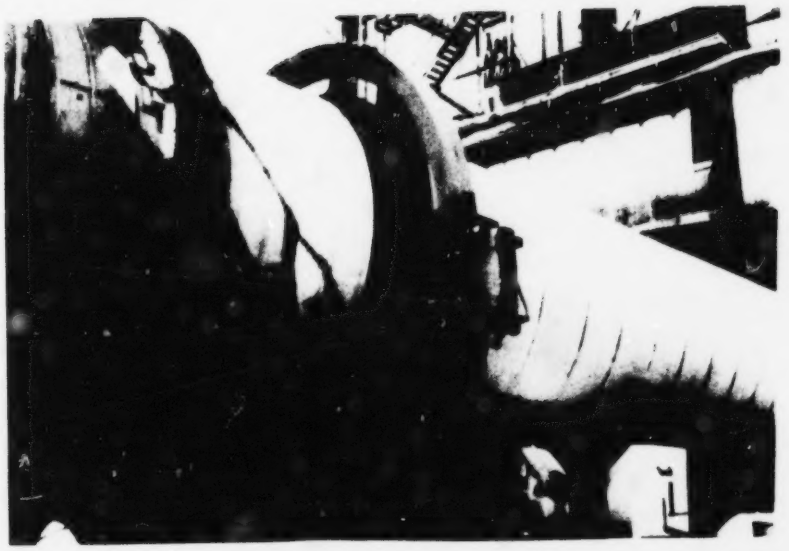


FIGURE 8: Ore Dryer with Cast Iron Drive Gears and Support Rollers

FIGURE 9: Close-up of Gears which Rotate the Ore Drying Kiln Shown in Figure 8

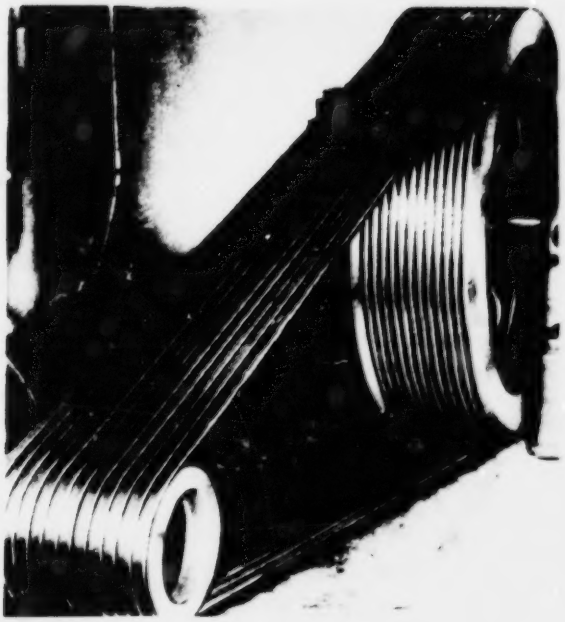


FIGURE 10: Multiple V-Belt Drive System with Cast Iron Pulleys (18)

location of repair

FIGURE 11: Cast Iron Drive Roll From Roll Crusher Which Has Been Repair Welded

After crushing, the ore may be further ground in rod mills and ball mills. Figure 12 is a ball mill with grey iron head castings. Figure 13 shows feed and discharge castings from a small grinding mill.

Large electrical motors are required to rotate grinding mills. Figure 14 is a motor, speed reducer and bearing for a rod mill. All of these components have grey iron housings. Figure 15 shows grey iron gear teeth which rotate a ball mill.

Figure 16 illustrates an electrical motor housing being repair welded (16).

Flotation is a common process used to concentrate finely ground minerals. Figure 17 shows two flotation cell impellers. The sheave used to rotate the impeller and the spindle bearing castings can be made of grey cast iron. Spare spindle bearing castings are shown in Figure 18.

Dewatering and water reclaimation from mineral slurries is often done in large settling tanks. Drive gears, such as the one shown in Figure 19, are used to rotate rakes in the thickeners. Gears and gear housings are made of grey cast iron. Desliming and dewatering can also be done in spiral classifiers as described in a case study to follow (Section 4.4).

A large number of conveyors are required to transfer ore between the various mineral processing operations. Figure 20 is a motor and speed reducer from an ore conveyor. The housings for both units are grey iron.

Figure 21 is an air compressor which was weld repaired at a quarry operation. The grey cast iron housing is still functioning satisfactorily,several years after serious cracks were repaired.

Various types of pumps are used to pump mineral slurries. The pump housings, bearing stuffing boxes and pedestal foundations for these pumps are frequently made of grey cast iron. Examples are shown in Figures 22 to 24.

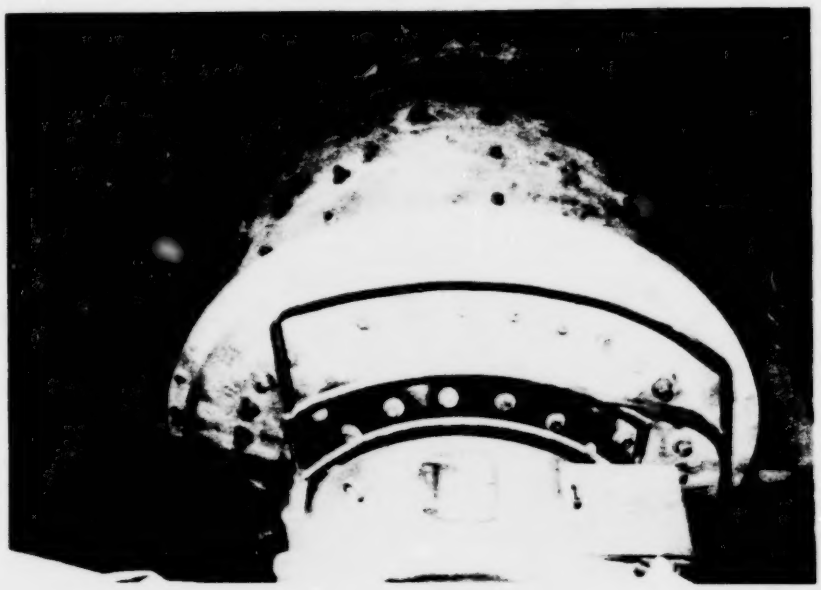


FIGURE 12: Ball Mill With Grey Iron Head Castings

FIGURE 13: Feed and Discharge Castings from a Small Grinding Mill

FIGURE 14: Motor, Speed Reducer and Bearings for Rod Mill Drive System- All Three Components Have Grey Iron Housings

FIGURE 15: Grey Iron Gear Teeth on End of Ball Mill

FIGURE 16: Motor Housing Being Repair Welded (17)

Top: Pneumatic hammer used for weld preparation

Bottom: Welding with nickel electrode

FIGURE 17: Two Flotation Cell Impellers with Grey Iron Sheaves and Spindle Bearing Castings

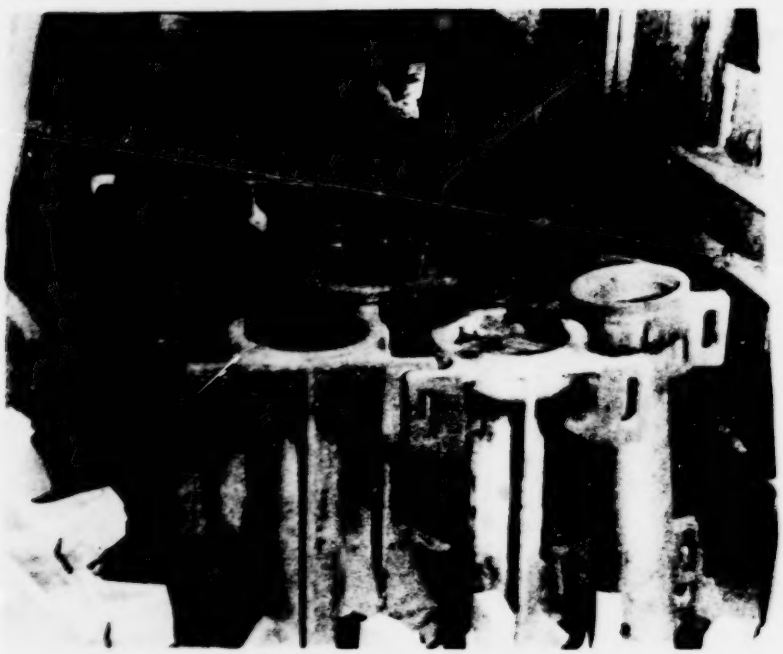


FIGURE 18: Spare Spindle Bearing Castings for Flotation Cell Impellers

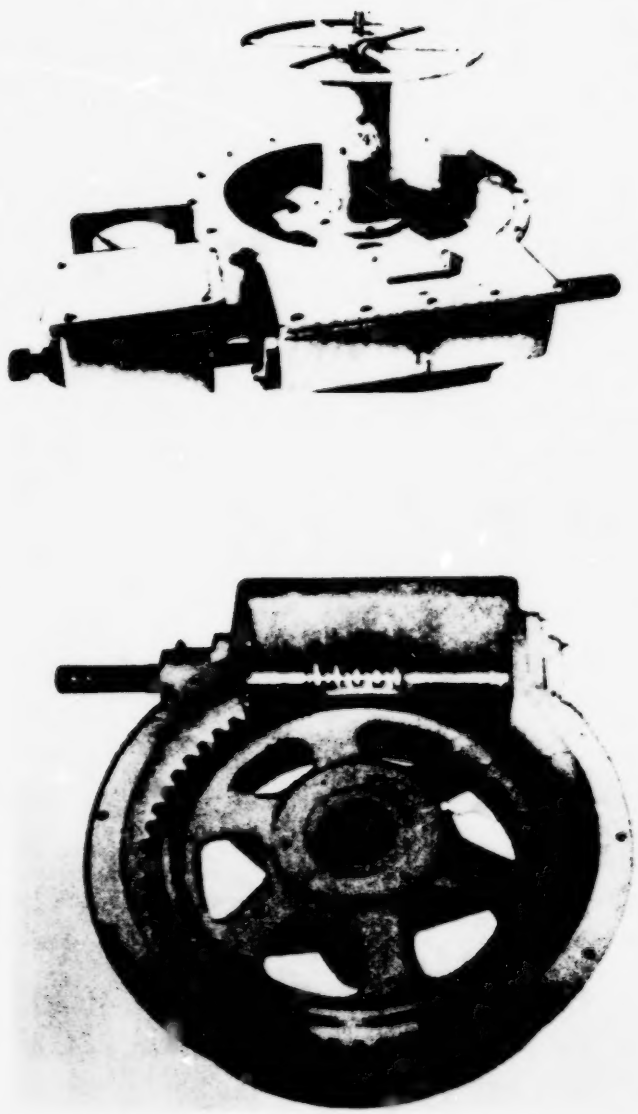


FIGURE 19: Drive Gear for Thickener with Gear and Gear Housing Made of Grey Iron (19,20)

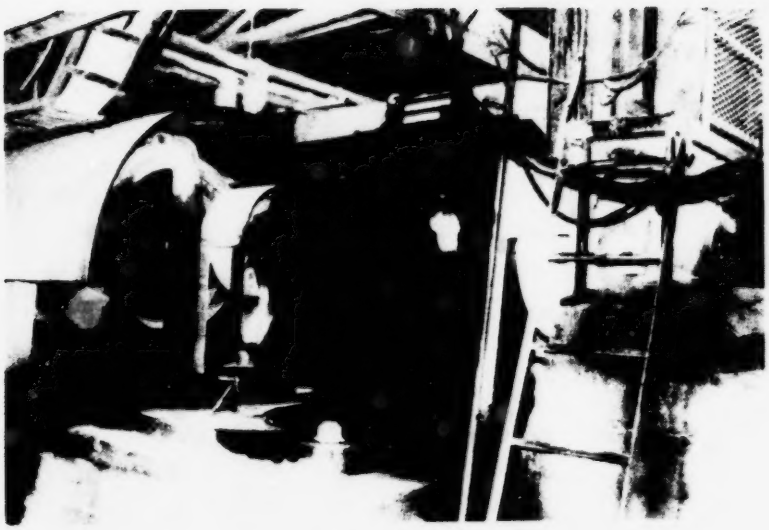


FIGURE 20: Motor and Speed Reducer with Grey Iron Housings - Used to Drive a Conveyor Belt

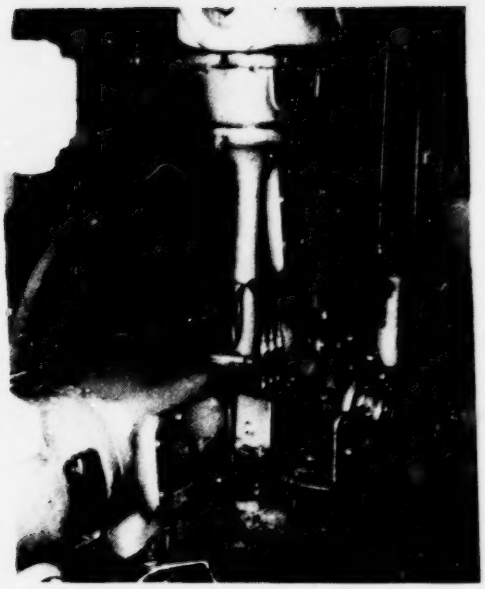


FIGURE 21: Air Compressor Which Was Repaired by Welding, after the Grey Iron Housing had Cracked

FIGURE 22: Diaphragm Pump with Grey Iron Housing is Used for Settling Tank Feed

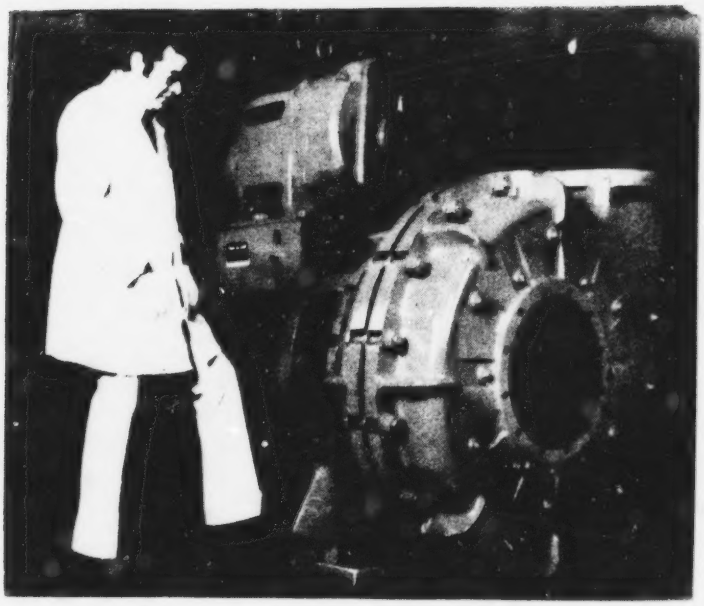


FIGURE 23: Rubber Lined Slurry Pump with Grey Iron Housing (22)

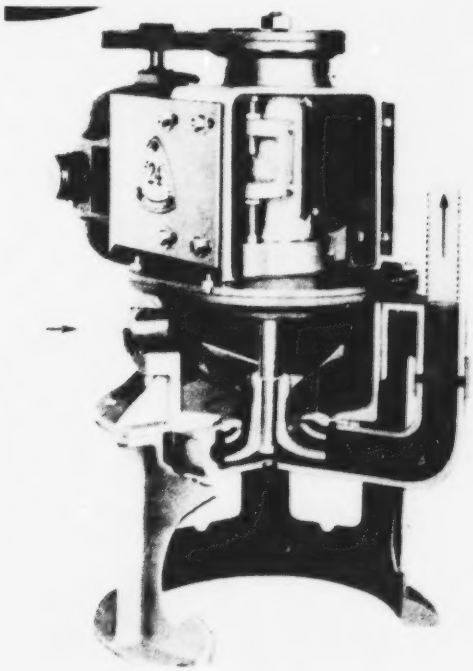


FIGURE 24: Vertical Sand Pump with a Cast Iron Bowl (23)

Remote mining operations must often generate their own electric power. Generator engine housings such as the one shown in Figure 25 are made of grey iron.

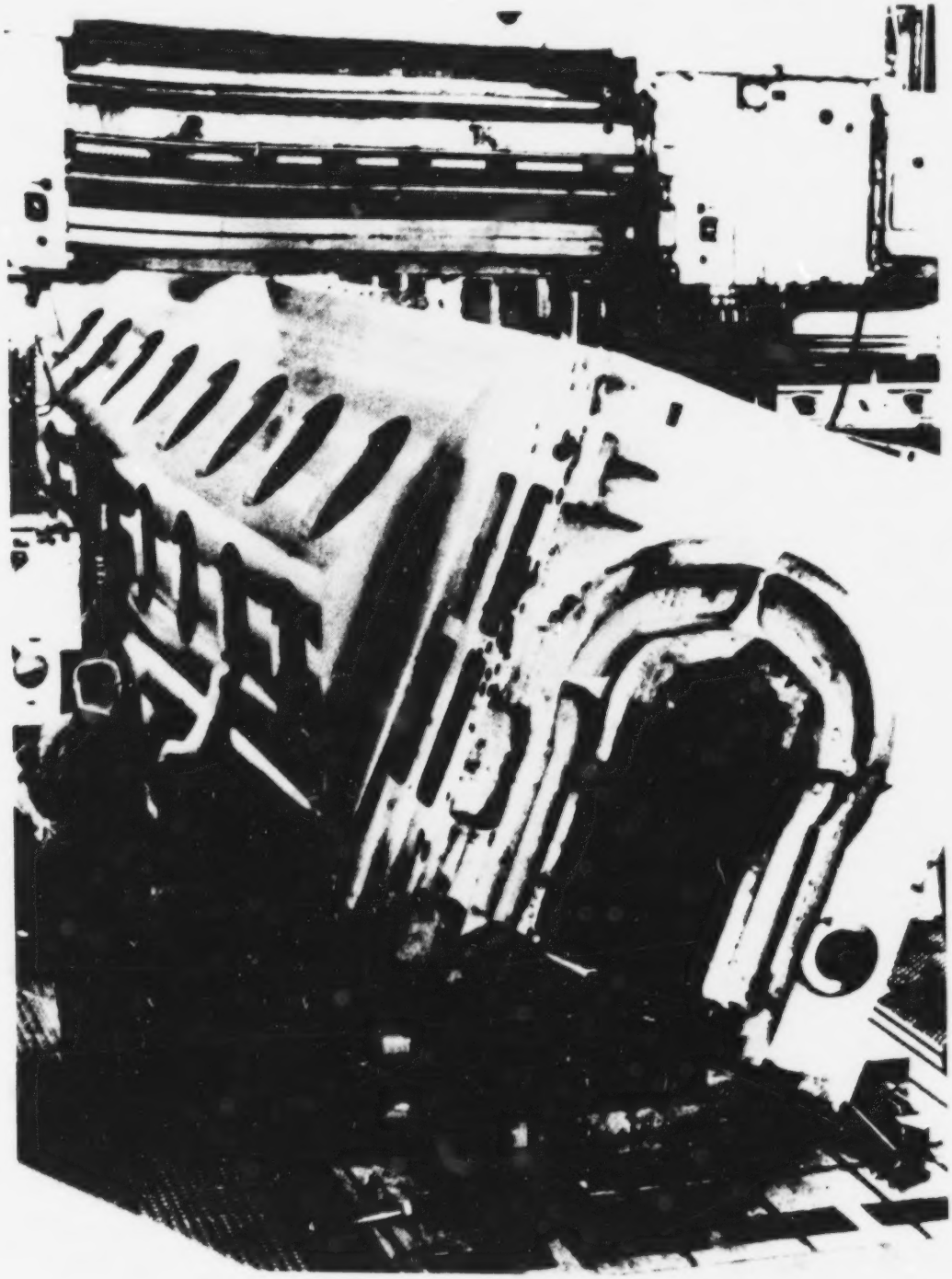


FIGURE 25: Diesel Engine Housing for Electric Power Generator (1)

After mineral processing at a milling operation, ore can be shipped to a metallurgical operation for conversion and refining to metal (see Figure 3). Metallugrical processing may include roasting. Figure 26 is an air blower which provides oxygen for fluid bed roasting.

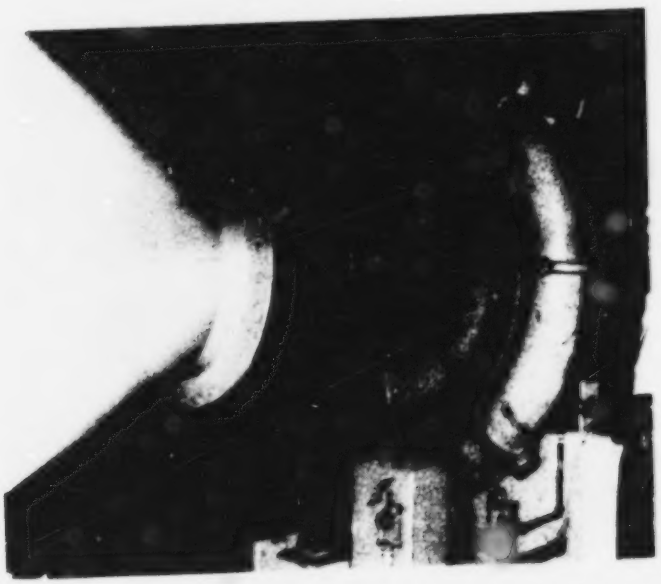


FIGURE 26: Air Blower for Fluid Bed Roaster with a Grey Iron Housing

Ore may have to be melted in large electric furnaces at a smelter. Figure 27 shows spare grey iron castings which are used for furnace launders in a smelting furnace. Ore may be further processed by refining in oxygen-blown vessels called converters. Figure 28 is a large motor and compressor used to provide air to converters. Both housings are grey iron.

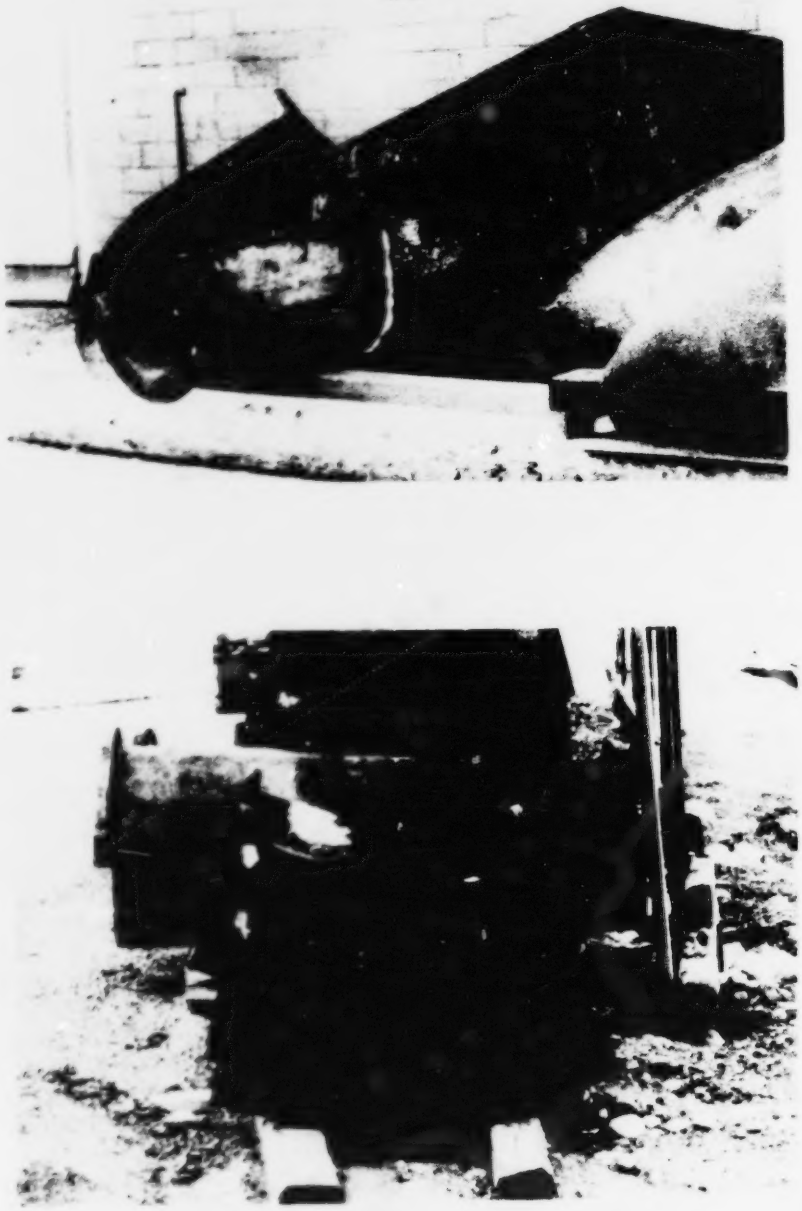


FIGURE 27: Grey Iron Castings Used for Launders On a Smelting Furnace

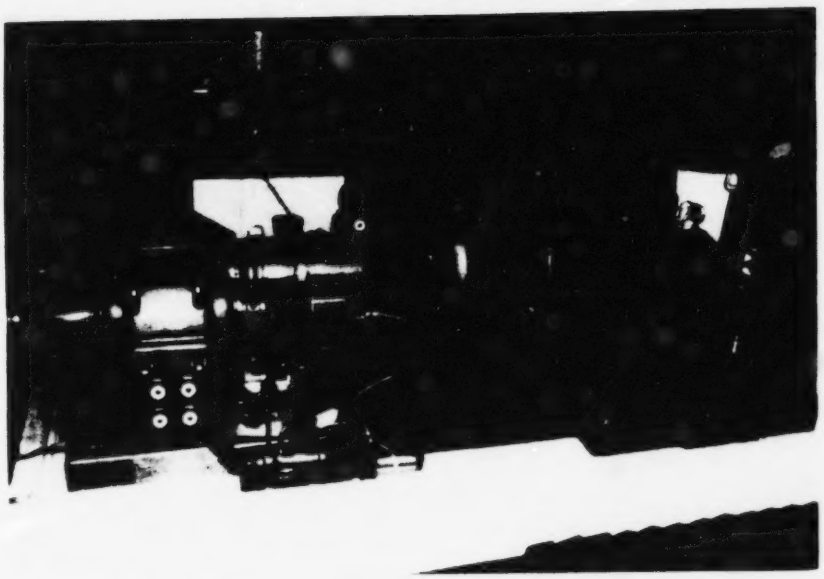


FIGURE 28: Large Motor and Compressor with Grey Iron Housings are Used to Provide Air to Converters

Ladle lips are often made of grey iron. Moulds used for casting matte are made of grey iron castings as shown in Figure 29. Gears for slag disposal ladles are also made of grey iron (Figure 30).

FIGURE 29: Matte Casting Moulds (Top) and Replacement Castings (Bottom)

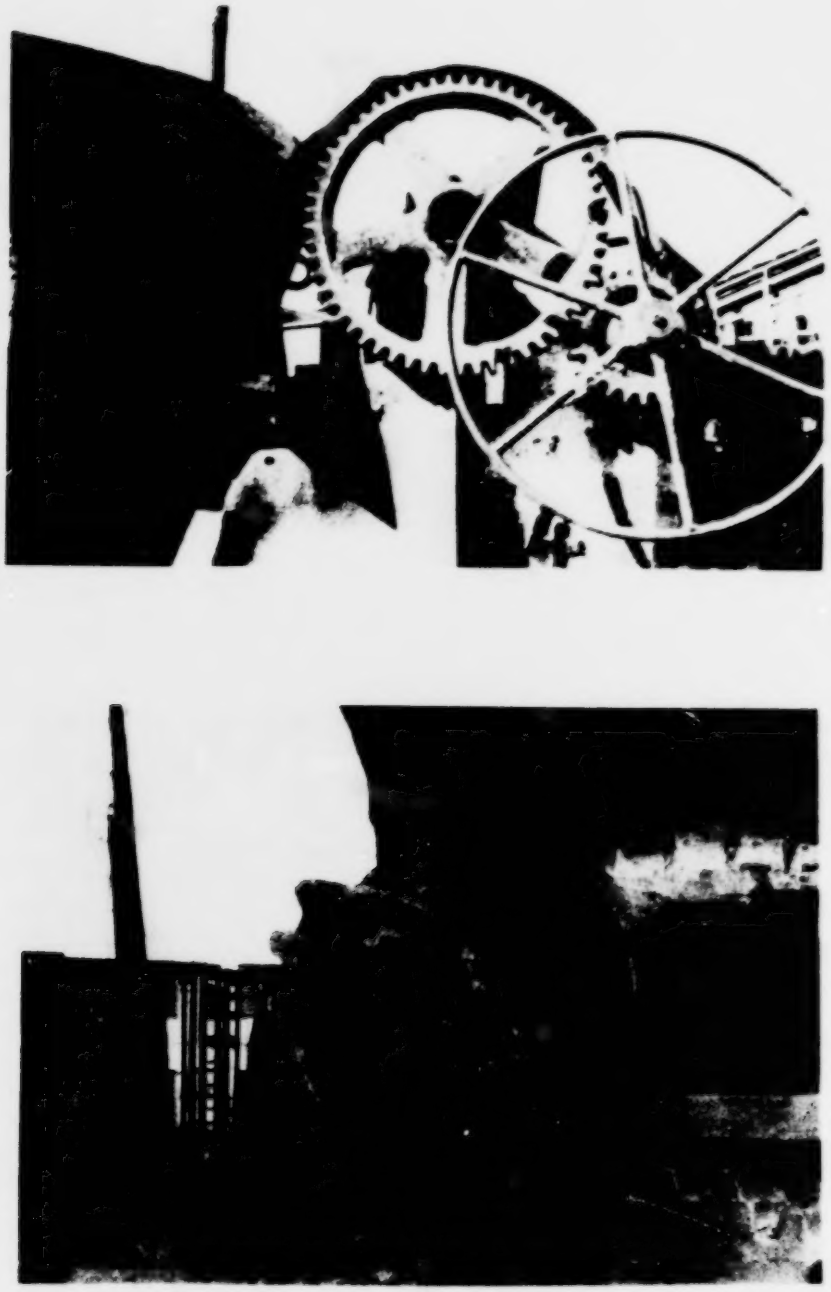


FIGURE 30: Gears and Tilting Mechanism for Slag Disposal Pots

Smelter gases are sometimes used to make acid in order to meet air quality standards. Ductile iron pipework is used extensively in sulphuric acid plants as shown in Figures 31 and 32.

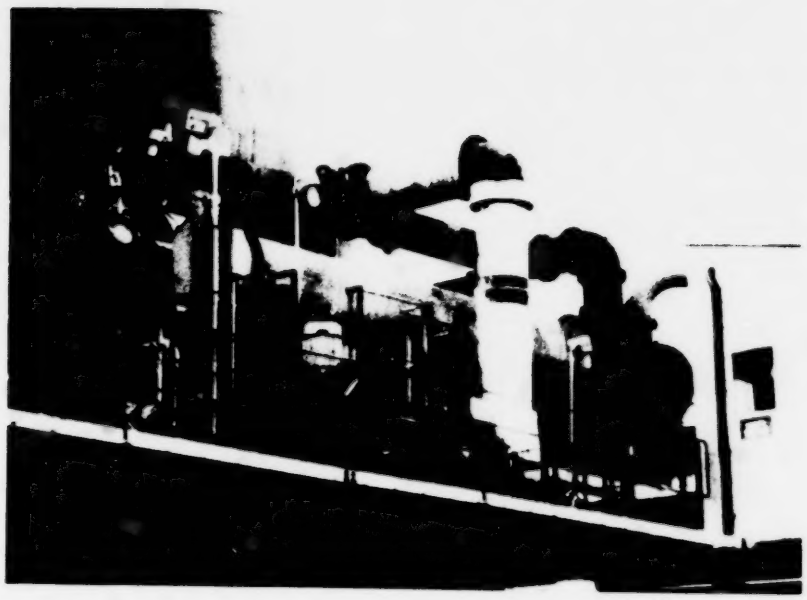


FIGURE 31: Ductile Iron Pipework for Acid Plant

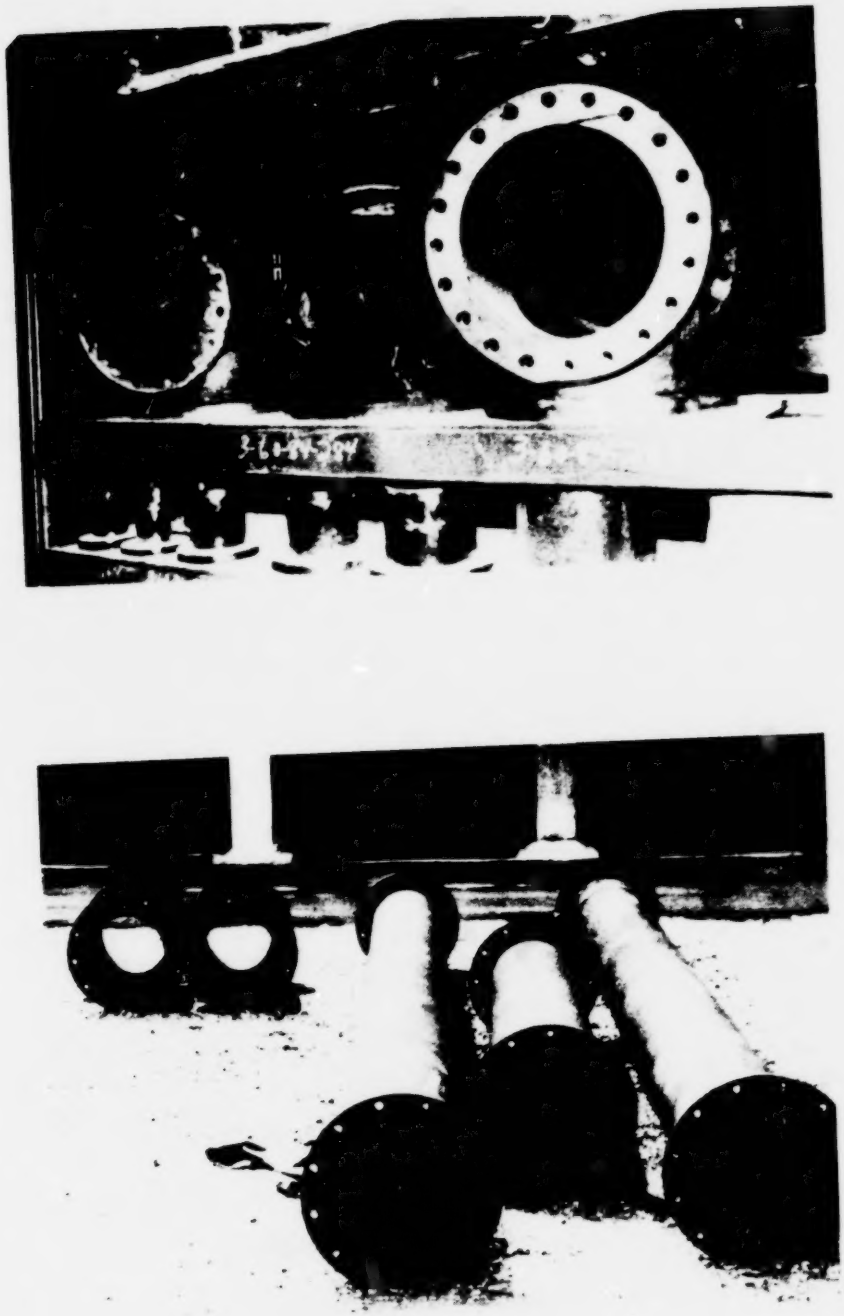


FIGURE 32: Ductile Iron Castings Used in Pipework for Sulphuric Acid Plant

The examples shown in Figures 4 to 32 illustrate the wide use of grey irons in mining operations. Effective maintenance procedures for these components is a critical aspect of plant operation. Reliable repair procedures are needed to help minimize production losses when unexpected failures occur.

3. GENERAL SMAW REPAIR PROCEDURE CURRENTLY RECOMMENDED FOR GREY CAST IRON

The procedure which follows is based on the published literature (1 to 8, 24 to 27) on this subject and repair experience at company operations. It should be realized that the repair of grey iron is difficult at the best of times and that this procedure is meant as a guideline only. Success at a given repair will depend on welder skill and experience, plus the specific nature of the failed component.

Table I lists the basic components of the recommended SMAW procedure. Further detail and rationale are given in the sections which follow.

TABLE I: Basic Components of Recommended SMAW Procedure

3.1	Identify material as low strength, flake graphite or ductile iron.
3.2	Visually inspect component and determine the feasibility of repair.
3.3	Clean parts of oil, grease, scale, rust or paint.
3.4	Use non-destructive inspection techniques to determine size, shape and termination fronts for all cracks.
3.5	Drill crack arrest holes at crack termination fronts.
3.6	Prepare all cracks using a modified U-groove design.
3.7	Preheat to 50°C and subsequently maintain temperature between 50 and 80°C.
3.8	Nickel electrodes are normally used for buttering layers and nickel-iron electrodes are used for some subsequent passes.
3.9	Store electrodes at 125°C, to keep dry when containers are opened.
3.10	Apply a thin nickel butter layer, peening each bead while still hot.
3.11	Apply root joining pass using short beads, peening each bead while still hot.
3.12	Reinforce root with two layers of nickel.
3.13	Fill groove using nickel, then nickel-iron for every third layer.

3.1 Material Identification

At present, it is only considered that the recommended procedure is suitable for grey irons with a tensile strength less than 345 MPa (50,000 psi). Ensure that the failed material is flake graphite iron or nodular graphite iron, by checking drawings or specifications. If these are not available, grinding tests and torch cutting tests can be used to distinguish between iron and steel. However, it is important to ensure that component is not made of white iron, high alloy iron or high strength iron. If one of these possibilities exist, a small section of the material should be sent to a laboratory for identification.

3.2 Initial Inspection

A thorough examination of the failed component should be carried out initially to determine the extent and nature of damage, in relation to the function of the failed part. This will dicate the type of action required. Several factors may make welding impractical, such as:

(1) Excessive thinning of the component due to corrosion, oxidation, erosion or wear.

(2) Castings which are subject to high stress, where the strength or durability of the repair weldments are not sufficient to meet the specified safety factors. A detailed stress analysis and weldment design may be required for critical applications.

(3) Parts prepared by precision machining, where postweld machining cannot be used to correct for distortion caused by the welding repairs.

(4) Inadequate accessibility to perform repairs satisfactorily.

3.3 Cleaning

Clean parts of any oil, grease, rust or paint to prepare for detailed inspection and welding. Cleaning can be done using a low residue degreasing solvent, high pressure hot water or steam or sand blasting. The best cleaning method will depend on the environment to which the component was exposed in service. For parts that have been immersed in light oil only, degreasing or high pressure spray cleaning may be adequate for inspection. However, when these parts are to be repaired, a subsequent grinding or wire brushing of the surfaces adjacent to the repair area may be required. In most cases cleaning by sand blasting is the preferred method, since heavy oil, grease, scale, rust and paint will be removed in one operation for both inspection and welding.

3.4 Non-Destructive Testing

Using dye-penetrant or magnetic particle inspection, determine the size, shape and termination points of all cracks. It is advisable to inspect fractured components on all sides to determine the orientation of cracks. This will facilitate weld preparation and give details required for positioning of crack arrest holes.

Measure worn areas and calculate weld metal required for repair and build-up. On components to be rebuilt, visual examination may be adequate, but areas which may have cracked should also be inspected by dye penetrant or magnetic particle inspection.

3.5 Crack Arrest Holes

The crack arrest holes are drilled prior to joint preparation, to prevent further crack propagation during gouging, grinding, welding and positioning. The hole serves to blunt the crack thus lowering the stress concentration at the crack tip. Drill holes at the termination of cracks, using a diameter appropriate for the thickness (i.e. 3 mm holes for 3 mm thickness and up to 19 mm holes for 75 mm thickness). The rationale for selecting hole size is not clear, but this practice is used successfully.

3.6 Joint Design and Preparation

The "Tulip" shaped preparation, shown in Figure 33, will allow sufficient area and accessibility for a buttering layer to be applied to the entire surface. For components subject to only static and compressive loading, it is only necessary to prepare the fractured or cracked parts to two-thirds of the material thickness, leaving one third not welded. This will provide sufficient static strength for moderately loaded components, but highly stressed parts require full penetration welding.

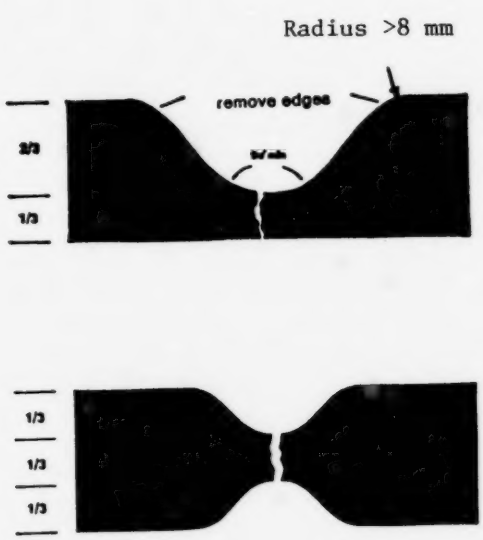


FIGURE 33: Joint Design - Modified U (Tulip) (24)

Top: Preparation for welding from one side
Bottom: Preparation for welding from both sides
Note: Full penetration weldments must be used for highly stressed parts, or when the loading conditions are not static and compressive.

Grinding, rotary burr or air arc gouging preparation methods can all be used for "U" groove type joints, but not for all material thicknesses. The risk of localized overheating, that could lead to additional cracking, is much greater on thinner material. Hence, air arc gouging should be restricted to material 12 mm or thicker. Gouging should be done in layers over the full length of the weld preparation, to ensure that the heat input remains uniform. Gouging to the full depth in one area is likely to result in additional cracks.

All prepared surfaces must be ground smooth for welding and to remove the hard martensitic zone formed during gouging. The top edges of the weldment preparation must also be ground to a minimum radius of 8 mm (see Figure 33). The "tulip" shape will help to minimize crack formation from welding.

3.7 Preheat and Interpass Temperatures

Preheat the weldment area to 50°C and maintain this temperature even between repair work shifts. Preheating to 50°C, will help to dry the weldment and avoid condensation of moisture on the workpiece. Avoid localiz ed heating, particularly where section thickness or geometry changes, since thermal shock can cause cracking. Thin sections may tend to overheat if burners are not used with care. Interpass temperatures should be kept below 80°C. Overheating (>80°C) should be avoided since cracking can result. The use of preheat temperatures in the range 50-80°C is referred to as "cold welding". Electric contact strip heaters, gas-fired or oil-fired torches can be used. Monitor temperatures with heat sensitive crayons or contact pyrometers.

3.8 Electrode Selection

Table II describes the recommended electrodes. Nickel electrodes (AWS classification ENi-CI) are primarily used for buttering layers. Specially modified electrodes, such as Ni-2 and Ni-3, are available to repair oily or difficult-to-weld castings. Nickel-iron electrodes (AWS classification ENiFe-CI) are used for some subsequent passes.

The AWS classification is not sufficient to select electrodes. There is good reason to believe that transfer characteristics and fluxing are important, rather than just deposit chemistry. At present, each consumable must be evaluated independently, but Phase II of this project will characterize superior electrodes, thus simplifying electrode selection in the future.

It is almost impossible to avoid the formation of a brittle heat affected zone when 'cold welding' grey iron. However, the depth and hardness of the brittle martensitic layer, plus subsequent tempering are influenced by electrode selection. This results from the arc and transfer characteristics of the specific electrodes, particularly for the nickel buttering layer. To minimize the depth of the brittle layer, the deposit should be thin and have little dilution from the cast iron. The thin layer will also help heat transfer and allow tempering of the brittle martensitic layer by subsequent welding passes. This will soften the brittle layer and help to avoid cracking.

TABLE II: Description of Electrodes Used to Repair Cast Iron (1)

Electrode Designation*	AWS 45.15 Classification (1)	Chemical Analysis	Comments
Ni-1	E Ni-CI	2.00% C max 4.00% Si max 1.00% Mn max 8.00% Fe max 85% Ni min 2.5% Cu max	-straight (DC-) polarity -spray type transfer shallow penetrating electrodes
Ni-2	E Ni-CI	same	-as Ni-1, but modified to minimize porosity when repairing oily casting
Ni-3	E Ni-CI	same	-similar to Ni-2, but deposit has sufficient iron to increase strength (approx. 7% Fe)
NiFe-1	E NiFe-CI	2.00% C max 4.00% Si max 1.00% Mn max 45.0 to 60.0% Ni 2.5% Cu max Fe balance	-straight (DC-) polarity -spray type transfer shallow penetrating electrodes
NiFe-2	E NiFe-CI	same as above but approximately 63% Nickel	-reverse (DC+) polarity -high deposition shallow -penetrating electrode -higher strength than Ni Fe-1

* These non-standard designations are used in this report to identify proprietary electrodes.

3.9 Electrode Storage

Low hydrogen electrodes are recommended, but once the electrode container is opened the rods must be stored in an oven at 125°C until used. Electrodes exposed for more than two hours should be redried in a separate oven for a minimum of 8 hours at 125°C.

3.10 Buttering Layer

The buttering layer provides a sound preparation for the joining operation. Do not attempt to join the crack with the buttering layer or cracks will form. Oil or moisture, which has soaked into the graphite of the grey iron is likely to cause cracking, porosity and poor bonding of the buttering layer. If any of these defects are present, all of the weld metal must be removed and a new buttering layer applied. It is sometimes necessary to repeat this procedure twice before a well-bonded layer is produced.

Use Ni-1 electrodes 2 mm in diameter (2.5 mm maximum) where possible. Electrodes Ni-2 or Ni-3 are used for very oily castings.

The staggered placement of beads will maintain a fairly uniform heat distribution and help to avoid thermal cracking. The use of small beads (50 mm x 6.3 mm x 1.5 mm, maximum) will also help to minimize local overheating. Immediately peen each bead while still hot with a manual or air-operated ball peen hammer. Satisfactory control can be achieved by using a pressure-regulated pneumatic tool similar to a slag descaling gun. Select a ball-headed tool to match the geometry and accessibility of the weldment. Peen lightly but thoroughly to produce a completely dimpled surface. The objectives are to redistribute the stresses produced by welding and to avoid cracking. Overpeening will cause underbead cracks and can even strip the buttering layer off the casting.

A buttering layer, similar to above, is required for rebuilding worn areas and the same general procedures can be used.

3.11 Root Joining Passes

Following the completion of the buttering layer, join the root using Ni-1 electrodes (3 mm diameter). Weld using short beads (<25 mm) and a slight weave (<1.5 x electrode diameter). Peen each bead lightly but thoroughly while still hot. Start the joining pass at the crack arrest hole where applicable. Stagger the weld beads to produce a uniform heat input and to avoid local overheating. Figure 34 shows the root joining pass and buttering layer.

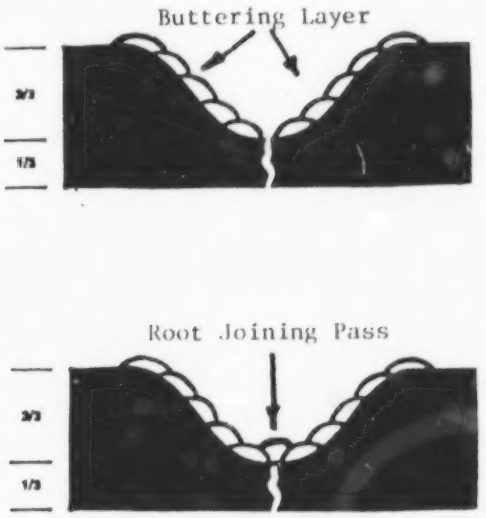


FIGURE 34: Root Joining Pass and Buttering Layer (24)

3.12 Root Reinforcing Beads

Build up the root area with two layers of nickel (approx. 4 mm deep) to act as reinforcement. Use Ni-1 electrode (3 mm or 4 mm diameter) taking the same precautions for bead deposition and peening used for the buttering layer (section 3.1.10).

3.13 Groove Fill Beads

Figure 35 shows the alternating sequence of fill beads used to avoid cracking in the large weldments. Nickel is used for the first fill layer (3 or 4 mm diameter) and subsequently nickel-iron is used for every third fill layer.

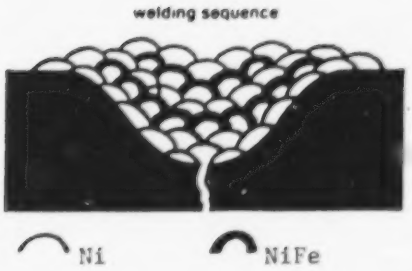


FIGURE 35: Alternating Sequence of Fill Layers Used to Avoid Cracking in Large Weldments (24)

Weld bead patterns and peening should follow the procedures outlined for buttering layers and root reinforcing beads (3.10 and 3.12). Each layer should start at the groove bottom and progress up each side to the top. A layer should not progress beyond the buttering layer or a fresh brittle zone will be produced. Each layer is meant to stress-relieve the previous layer and help to avoid cracking.

3.14 Arc Strikes

Welding operators should be instructed to strike the arc immediately ahead of the point where they intend to start the weld bead, then move back rapidly to where they intend to start the weld and proceed over the arc strike area in a normal manner. Arc strike areas, because they are quenched so drastically produce a hard brittle martensitic surface, and if not welded over can be sites for crack initiation. At no time should the arc be struck on surfaces away from the line of welding.

4. CASE STUDIES

4.1 Repairs to Primary Crusher Main Frame (Open Pit Mine)

4.1.1 Technical Function of Failed Part

A used Bulldog type 106.7 cm x 122 cm Traylor Jaw Crusher was purchased for use as a primary crusher in an open pit mine, that was under construction. The main frame of the crusher was cracked at the time of the purchase, but the cracks were undetectable due to a thick lime deposit. The main frame is the superstructure of a crusher which supports all of the components that perform the crushing action. Figure 36 shows a cross-section through a jaw crusher similar to the type that was purchased. Figure 37 shows the dismantled cast iron main frame bottom side up.

4.1.2 Description of Failure

Following high pressure water and sand blast cleaning operations to remove the lime deposit, inspection revealed that the 5 m long by 1.7 m wide, 40 ton main frame had cracked extensively on both sides in the swing jaw suspension area. The cracks were located in the link support collar of the main frame. The collar supported the horseshoe shaped steel link which contained both swing jaw bearing bases. It was necessary to remove the zinc-mounted upper link to carry out a more thorough inspection. The frame was of a double wall construction with the outer wall solid and inner wall having open port holes between reinforcing ribs. Figure 38 is a cross-section through the frame showing the double wall construction.

Dye penetrant examination revealed that the cracks had initiated in the radius of the upper swing jaw suspension area, and had propagated to the outside and inner walls. The cracks on the outside walls had progressed down to the radius of the link support collar and had propagated for approximately one metre. The cracks on the inside wall had progressed down through the inner wall to an open port. Material thickness in the area of the cracks ranged from 2.5 cm to 18 cm. Figure 39 shows the location of the cracks on both the outside and inner frame walls. Photographs of the dye penetrant examination of the outside and inside frame walls are shown in Figure 40.

4.1.3 Welding Procedure Used

The welding procedure that was used for the repair complied to that outlined in the General Procedure, Section 3, with the following exceptions and details.

Crack arrest holes of 19 mm diameter were drilled at the termination points of the cracks on both sides of the frame.

Air arc gouging followed by grinding of the gouged surfaces were used to prepare a double "U" groove joint design. The depth of each groove was one third the material thickness leaving one third not welded. On the 2.5 cm thick sections the "U" groove joint was prepared with a 0.6 cm root radius and 0.8 cm radius on the top edges of the groove. On the 75 cm thick sections, a 1.3 cm radius was used for the root and top edges of the groove.

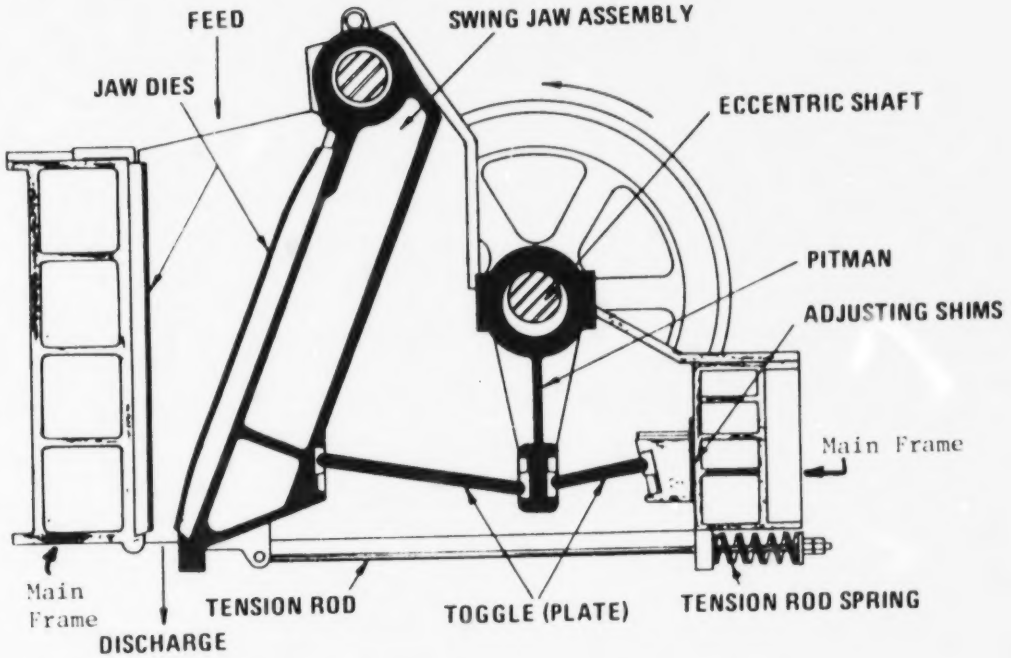


FIGURE 36: Cross-section of a Jaw Crusher Showing the Crushing Components (28)

FIGURE 37: Dismantled Main Frame of Jaw Crusher-Bottom Side Up

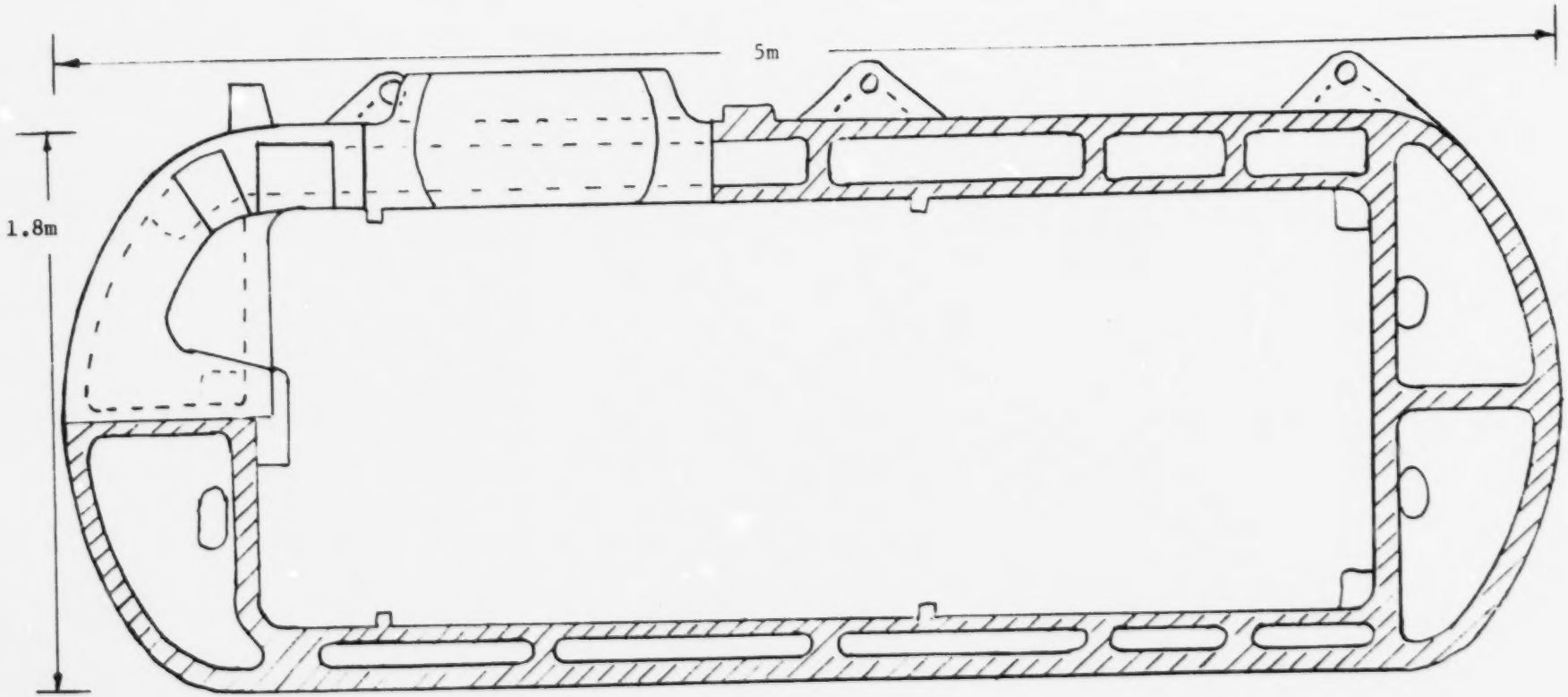


FIGURE 38: Top View of Cross-section through Crusher Frame, showing Double Wall Construction

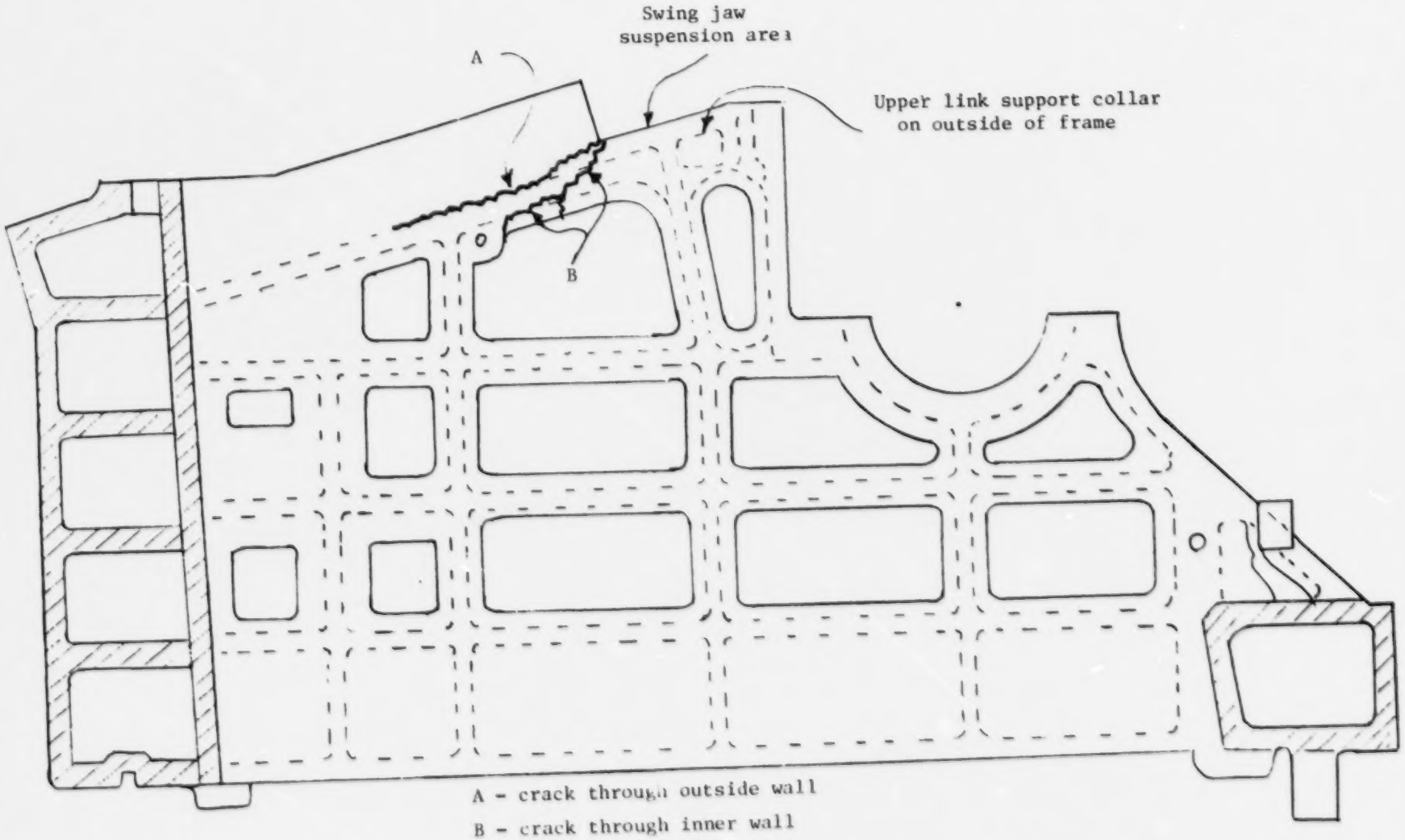


FIGURE 39: Side View of Cross-section Through Length of Crusher Frame showing Location of Outside and Inside Cracks

Outer Wall

Inner Wall

Outer Wall

Inner Wall

FIGURE 40: Dye Penetrant Examination of Outer and Inner Walls on Both Sides of the Crusher Frame

Ni-1 electrodes of 2.5 mm diameter were used for the buttering layer and 3 mm diameter for the root reinforcing layers plus the first to third fill layers. Electrodes of 4 mm diameter were used for the remaining fill layers. Type NiFe-1 (3 mm diameter) was used for the first layer and 4 mm diameter for the remaining alternating layers.

No difficulties were encountered in producing a porosity free buttering layer with a good bond.

The "U" groove was prepared to one third depth on one side only, then buttered and welded completely before preparing the second side. The frame was turned when necessary throughout the repair, to enable the major portion of the welding to be carried out in the flat or horizontal positions. Welding in the vertical position was limited to two short lengths of grooves on the inner wall of the frame.

The preheat temperature was maintained on the frame in the areas of repair between work shifts, using electric strip heaters placed on the outer and inner walls. This procedure eliminated the need for preheat at the start of the shift and maintained the area of repair at a uniform temperature.

Figure 41 shows a groove in the air arc gouged condition and after grinding smooth for welding. Completed weld repairs to the outer and inner walls from both sides of the frame are shown in Figure 42.

4.1.4 Cost Effectiveness of Repair in Comparison to Replacement

The total cost of the weld repair including welding labour and welding consumables was $10,500. The entire repair was completed over a two month period.

Quotations indicated that a new crusher would cost $250,000 with a delivery of 12-18 months. A new frame would have cost $40,000. with a similar delivery quoted. With this delivery, plant startup would have been delayed by 6 to 8 months causing an unacceptable production loss approaching $1,000,000.

Another possibility would have been to purchase a used crusher at a cost of approximately $100,000 from another source. However, this would have meant tearing out the existing foundation and building one suitable for the replacement crusher. This foundation work would also have been expensive.

Hence, the repair welding saved at least $100,000, in comparison to replacement with a used crusher.

Groove as Gouged Condition

Groove After Grinding Smooth

FIGURE 41: "U" Groove in Air Arc Gouged Condition and after Grinding Smooth, Prior to Welding

Outer Wall

Inner Wall

Outer Wall

Inner Wall

FIGURE 42: Completed Weld Repair of Outer and Inner Walls on Both Sides of Crusher Frame

4.2 Repairs to Ball Mill Gear Reducer Housing (Milling Circuit)

4.2.1 Technical Function of Failed Part

The failure of a gear reducer housing in a plant milling circuit stopped production of a primary ball mill incurring a substantial daily product loss. The gear reducer served as a speed reducer between the 800 HP electric drive motor for the 3.5 metre diameter by 4.3 metre long ball mill. Figure 43 shows a ball mill, with speed reducer and electric drive motor similar to the above type.

4.2.2 Description of Failure

Initial inspection revealed that the one ton grey cast iron gear housing (120 cm long by 46 cm wide by 100 cm high) had developed cracks in the lower and upper sections. The unit was completely dismantled and required a thorough degreasing to remove the gear lubricating oil from the surface, before a more complete evaluation of the damage could be made.

Magnetic particle inspection revealed that the cracks had initiated in the high speed shaft bore collar and had progressed approximately 30 cm in length into the lower section, and approximately 120 cm in length into the upper section. Figure 44 shows the path of the cracks through the shaft bore collar and into the lower and upper housing shell. The material thickness in the bore collar was approximately 7.6 cm and in the housing shell approximately 1.3 cm.

Examination of the gears revealed that a section of gear tooth had broken off and had been trapped between the gears on the high speed side. The resultant forces on the shaft collar led to the failure of the gear housing.

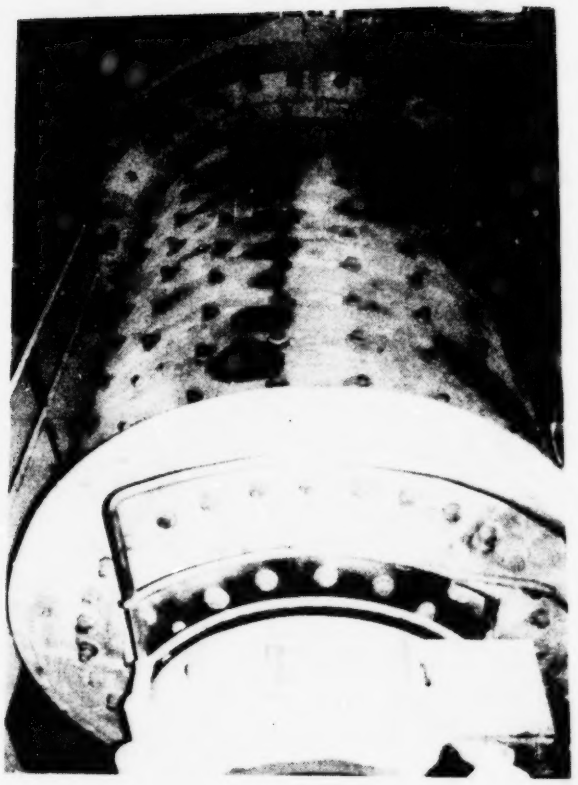
4.2.3 Welding Procedure Used

The welding procedure that was used complied to that outlined in the General Procedure Section 3 with the following exceptions and details.

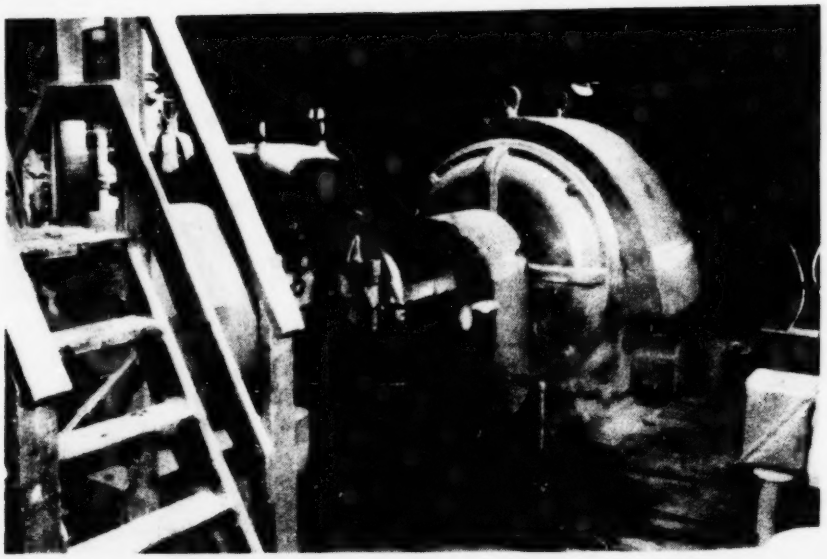
Crack arrest holes of 1.3 cm diameter were drilled at the termination points of the cracks in the lower and upper housing sections.

Prior to the start of joint preparation and weld repairs, the two sections were bolted together to minimize the risk of distortion during the above operations. As an added precaution, a single "U" groove with a depth of two thirds of the material thickness was used on the collar cracks and outside shell cracks, so that most of the welding would be done while the two sections were bolted together. As a result, upon completion of the outside repairs, only a shallow inside groove required welding.

Air arc gouging followed by grinding of the gouged faces was used to prepare the single "U" groove on the outside shell and collar cracks. On the 1.3 cm thick sections the "U" groove was prepared with a 0.4 cm root radius and 0.3 cm radius on the top edges of the groove. On the 7.6 cm thick bore collar sections a 1.3 cm radius was used for the root and top edges of the groove.



Ball Mill



Speed Reducer and Drive Motor

FIGURE 43: Ball Mill with Speed Reducer and Drive Motor, Similar to the Type Used in the Milling Circuit

Upon completion of the outside repairs, the two housing sections were parted and the inside grooves prepared by grinding only. The 1.3 cm thick sections were prepared to a depth of 0.3 cm with a 0.3 cm radius at the top edges. A groove depth of 1.3 cm was prepared on the collar only where accessible. In areas of poor accessibility, the inside cracks were left unwelded.

Ni-1 electrodes, 2.5 mm diameter, were used for the buttering layer on the housing shell cracks but Ni-2, 2.5 mm diameter electrodes were required for the buttering layer in the collar grooves due to excessive porosity and poor bonding. It was necessary to remove the first buttering layer completely because of porosity even when using the Ni-2 electrodes. The second buttering layer was free of porosity and bonded well.

Ni-1 electrodes, 3 mm and 4 mm diameter, were used for the remaining layers in combination with NiFe-1 electrodes 3 mm and 4 mm diameter electrodes as outlined previously for multi-layer deposits (3.13).

The gear reducer was turned when necessary throughout the repair to enable all welding to be carried out in the flat or horizontal positions.

Repairs were carried out on a two 12 hour shift bases, thus automatically maintaining preheat and interpass temperature.

Figure 45 shows a partially filled collar groove weld and welding in progress on the upper collar groove with the gear case upside down. Figure 46 shows the completed outside repairs on the shell cracks and collar cracks.

4.2.4 Cost Effectiveness of Repair in Comparison to Replacement

The total cost of the weld repair including welding labour, welding consumables, machining and replacement gears was $14,100. The entire repair took eight days to complete, from the time of failure to when the unit was placed back into service.

A new gear reducer was quoted to cost $14,572 with a delivery of six weeks. With this delivery, a six week production loss would have amounted to approximately $1,500,000.

Fortunately, it was possible to substitute a gear reducer with an identical housing that was being used on a ball mill in a secondary milling circuit to the primary cirucit while the cracked unit was being repaired. The substitution had resulted in a four day loss of production of $52,000. Had the substitution not been possible the total production loss during the repair period would have amounted to $104,000.

Thus the repair welding saved at least $1,434,000 with the use of a substitute gear reducer housing that was on the property and up to $1,382,000 had there not been a substitute available. Production losses could not be redeemed because of high demand and delivery schedules.

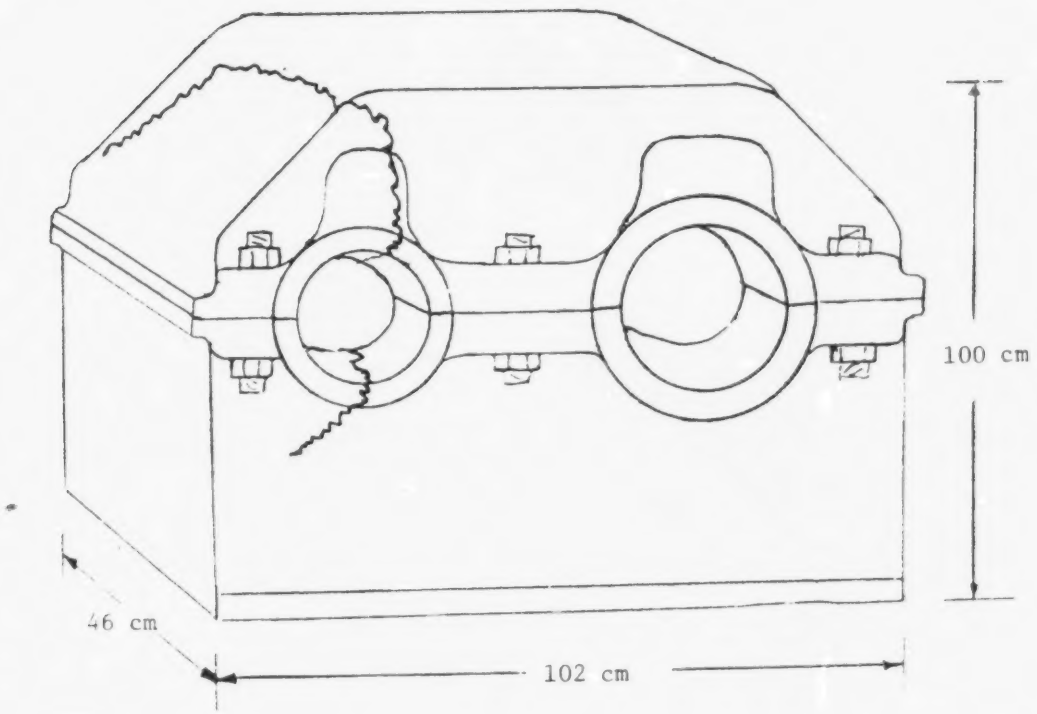
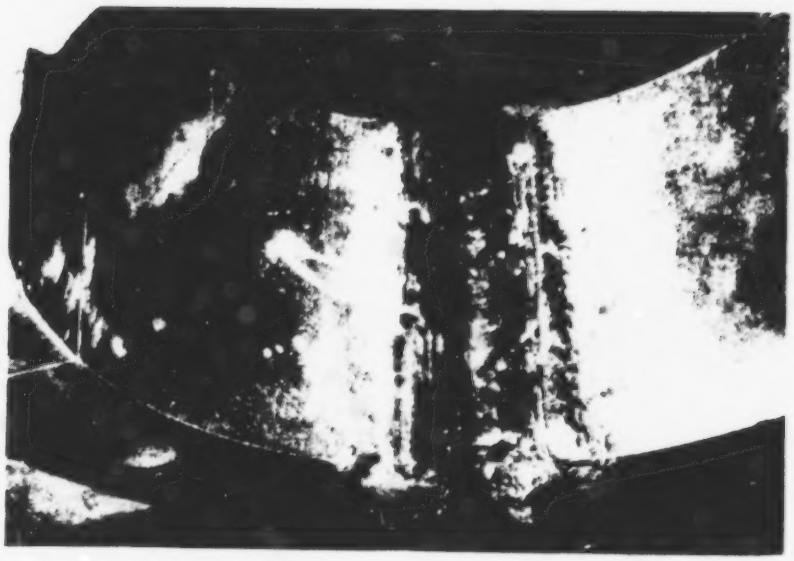


FIGURE 44: Sketch of Gear Reducer Housing Showing the Location of the Cracks in the Bottom and Upper Half



Partially Filled "U" Groove in Collar

Welding Collar Groove in Upper Section

FIGURE 45: Partially Filled "U" Groove (Top) and Welding in Progress on Collar Groove in Upper Gear Housing Section

FIGURE 46: Complete Weld Repair on Outside Shell and Collar Grooves

4.3 Build-up of Matte Crusher Swing Jaw (Smelter)

4.3.1 Technical Function of Failed Part

The swing jaw of a 46 cm by 76 cm Baxter jaw crusher, that is used to crush matte, was removed from service. Excessive wear had occurred on the crushing face that was in contact with the underside of the wear plate. The jaw crusher consists of two crushing surfaces, one fixed or a stationary jaw, the other a movable or swing jaw. The movable jaw pivots on a shaft at the top of the jaw and is caused to oscillate at the bottom by the action of toggles and pitman that are actuated by the eccentric shaft. The product progresses by gravity between the jaws and is crushed by the pressure exerted by the oscillating action. Figure 36 in section 4.1 shows a cross-section through a jaw crusher similar to the matte crusher and illustrates the various components in the crushing action.

The bolts holding the wear plates to the swing jaw in the matte crusher had worked loose thus allowing the wear plate to hammer and wear against the face of the swing jaw during the crushing action. Figure 47 shows a grey iron swing jaw with a wear plate bolted to the crushing face similar to the type that is used on the matte crusher.

4.3.2 Description of Failure

Inspection after sand blasting revealed that the wear area was in the lower portion of the jaw face and was in the shape of a wedge, 2.5 cm in depth at the bottom and tapering to zero at the upper portion of the worn area. The wear had extended over the full 74 cm width of the jaw face and up to a point 130 cm from the bottom of the jaw. Figure 48 shows the wear profile on the crushing face of the swing jaw.

Examination of the worn area revealed a flaky surface probably as the result of the hammering by the loose wear plate. Magnetic particle inspection of the full crushing face revealed no cracks.

4.3.3 Welding Procedure Used

The repair welding procedure used complied to that outlined in the General Welding Procedure, Section 3, with the following exceptions and details.

Prior to welding, a 3 mm thick layer of material was removed from the worn area to ensure that the weld metal would be deposited on sound material rather than the flaky surface.

FeNi-1 electrodes were used for the entire build-up. Electrodes 2.5 mm and 3mm diameter were used for the buttering layer and 3 mm and 4 mm diameter were used for the remaining layers. The weld bead deposition procedure for the build-up was the same as described in the General Procedure for groove fill beads with the exception of the electrode type used.

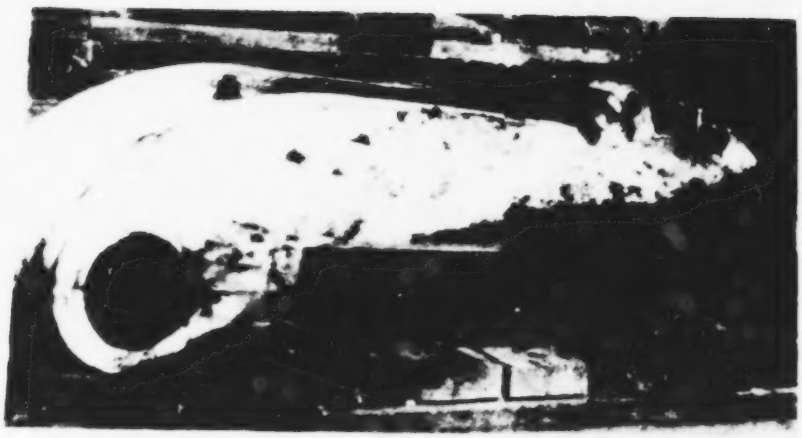


FIGURE 47: Swing Jaw with Wear Plate Bolted to the Crushing Face, Similar to the Type Used on the Matte Crusher

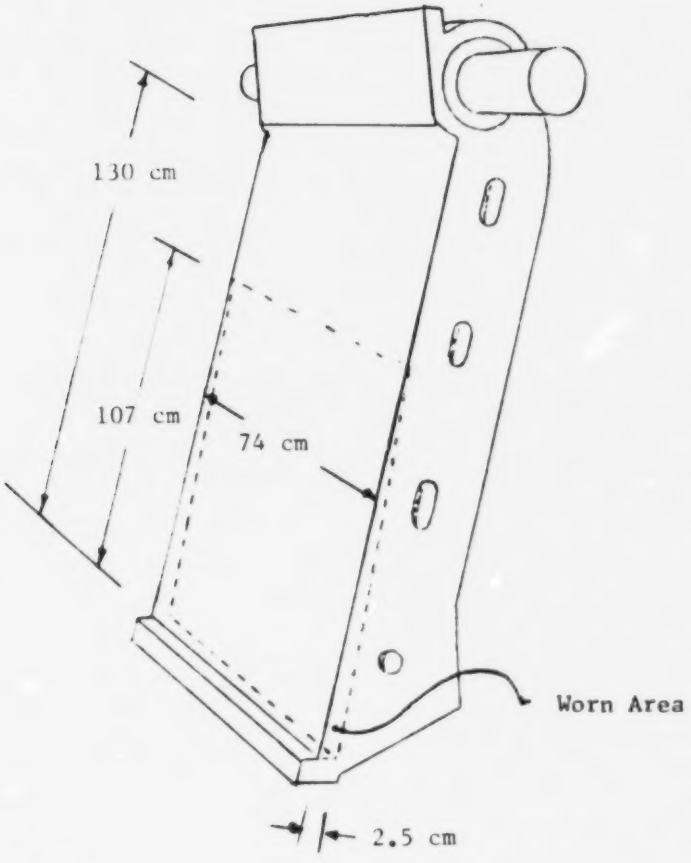


FIGURE 48: Wear Pattern on the Lower Section of the Crushing Face, Under the Wear Plate of the Matte Crusher Swing Jaw

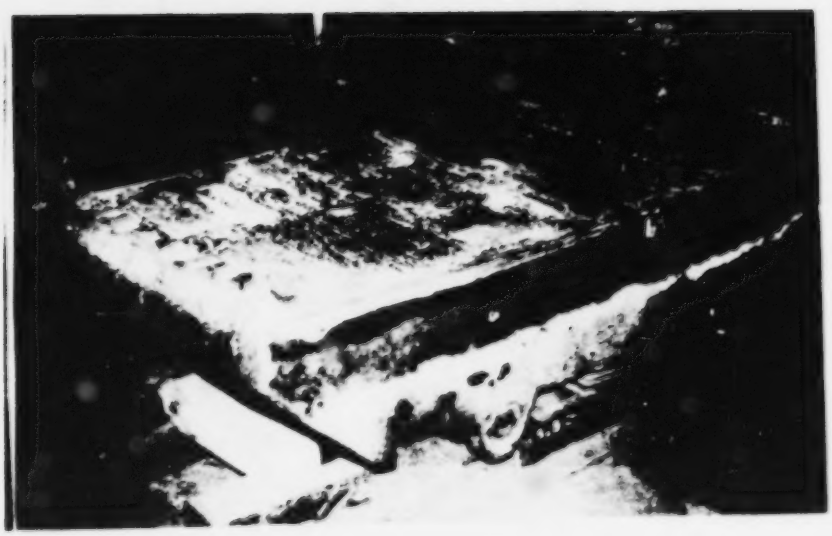


FIGURE 49: Swing Jaw from Matte Crusher Showing Completed Weld Build-up Using Nickel Iron Electrodes

The preheat temperature was maintained on the complete swing jaw between work shifts using electric strip heaters placed on the faces of the jaw. This procedure eliminated the need for preheat at the start of the shift and maintained the part at a uniform temperature at all times.

The worn face of the swing jaw was positioned to enable all welding to be done in the flat position. Figure 49 shows the swing jaw with the worn area completely built-up.

4.3.4 Cost Effectiveness of Repair in Comparison to Replacement

The total cost of the weld repair including welding labour and welding consumables was $6,150. The entire build-up took one month to complete on a one welder per 8 hour shift, one shift per day basis. The build-up was considered low priority as a used identical swing jaw was available to place in service while the worn unit was being repaired.

A new swing jaw was quoted to cost $12,000 with a delivery of one month. Thus the repair saved $5,850. The repairs to the swing jaw were carried out purely on an economic basis of replacement cost versus repair costs, since production was not affected.

4.4 Repairs and Build-up of a Classifier Gear (Quarry)

4.4.1 Technical Function of Failed Parts

A spiral classifier which is used to dewater and deslime the crushed product at a quarry had failed resulting in a production stoppage. The classifier drive gear had fractured through the teeth of the outer gear ring and two support spokes. Figure 50(A) shows spiral classifiers in a typical production operation. Figure 50(B) shows a spiral classifier plus the spiral which moves the product in the trough. Figure 50(C) is a close up of a similar classifier drive unit, showing the drive gear with the gear teeth on the outer drive ring, and the support spokes through which the fracture had occurred.

4.4.2 Description of Failure

Before a proper inspection could be made to assess the damage, it was necessary to degrease the gear and sand blast to remove the thick lubricating grease that was caked on all of the surfaces. Inspection of the cleaned gear revealed that a 60 cm long section had broken off the 139 cm diameter grey cast iron gear ring. The fracture had taken place through the 12.7 cm wide outer gear ring in the root radius between the teeth and through two of the 7.6 cm wide support spokes. It was also noted that all of the 96 teeth on the drive ring had worn approximately 1 cm over the full 12.7 cm width on the faces that were in contact with the drive pinion during operation. Magnetic particle inspection of the complete gear revealed no additional cracks. Figure 51 shows the location of the fractures plus the wear pattern on the teeth.

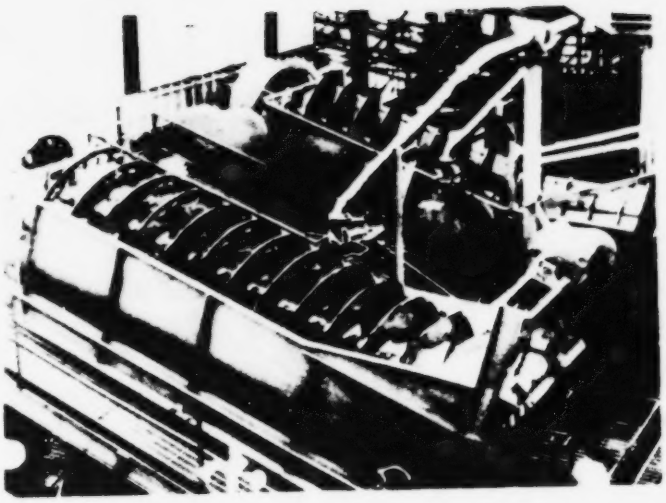
4.4.3 Welding Procedure Used

The welding procedure used for the repairs complied to that outlined in the General Welding Procedure, Section 3, with the following exceptions and details.

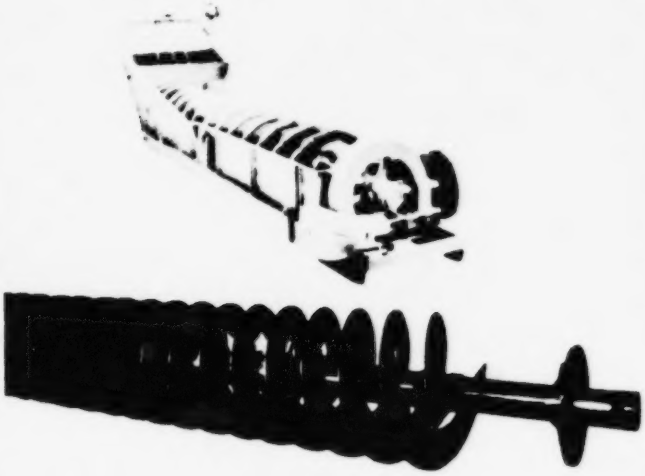
Crack arrest holes were not required on the gear as all fractures extended through complete sections.

All fractured surfaces were prepared to a double "U" groove complete penetration joint design by grinding. The root radius was 0.5 cm and the root land 0.3 cm. The broken piece was then fitted to the gear and both sections bolted to a 2.5 cm thick strong-back made of carbon steel plate, which was slightly larger than the gear. This plate helped to prevent distortion and maintain the shape of the gear during welding. Access holes were cut in the strong-back so that all welding could be completed before the gear was removed from it. Upon completion of the first side of all fracture points, the second side was ground to sound metal and the joint completed. The gear was then removed from the strong-back for build-up of the worn areas of the gear teeth.

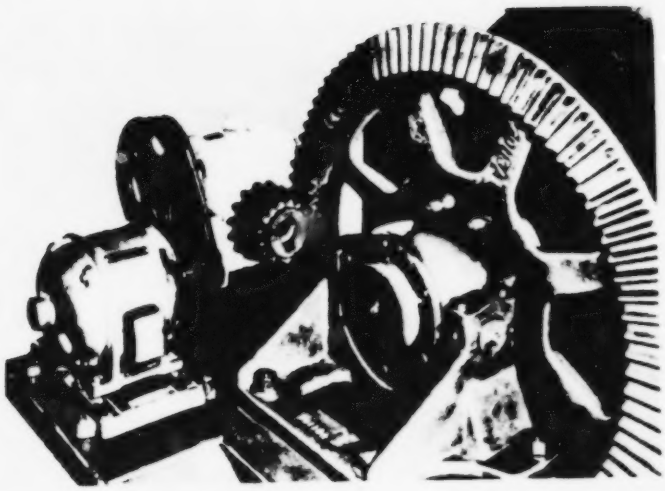
Ni-2 electrodes (2.5 mm diameter) were used for the buttering layer on the faces of the "U" groove, to produce porosity free welds with a good bond. The Ni-1 electrodes were tried but could not be used due to excessive porosity in the welds. Ni-1 electrodes (3 mm and 4 mm diameter) were used for the remaining layers in combination with NiFe-1 (3 mm and 4 mm diameter) electrodes as outlined previously for multilayer welds.



(A)



(B)



(C)

FIGURE 50: Spiral Classifier Components

(A) Classifiers in a typical production operation (29).

(B) Classifier and spiral screw (29).

(C) Close-up of a similar classifier drive unit showing the drive gear with the gear teeth on the outer drive ring and support spokes through which the failure had occurred (30).

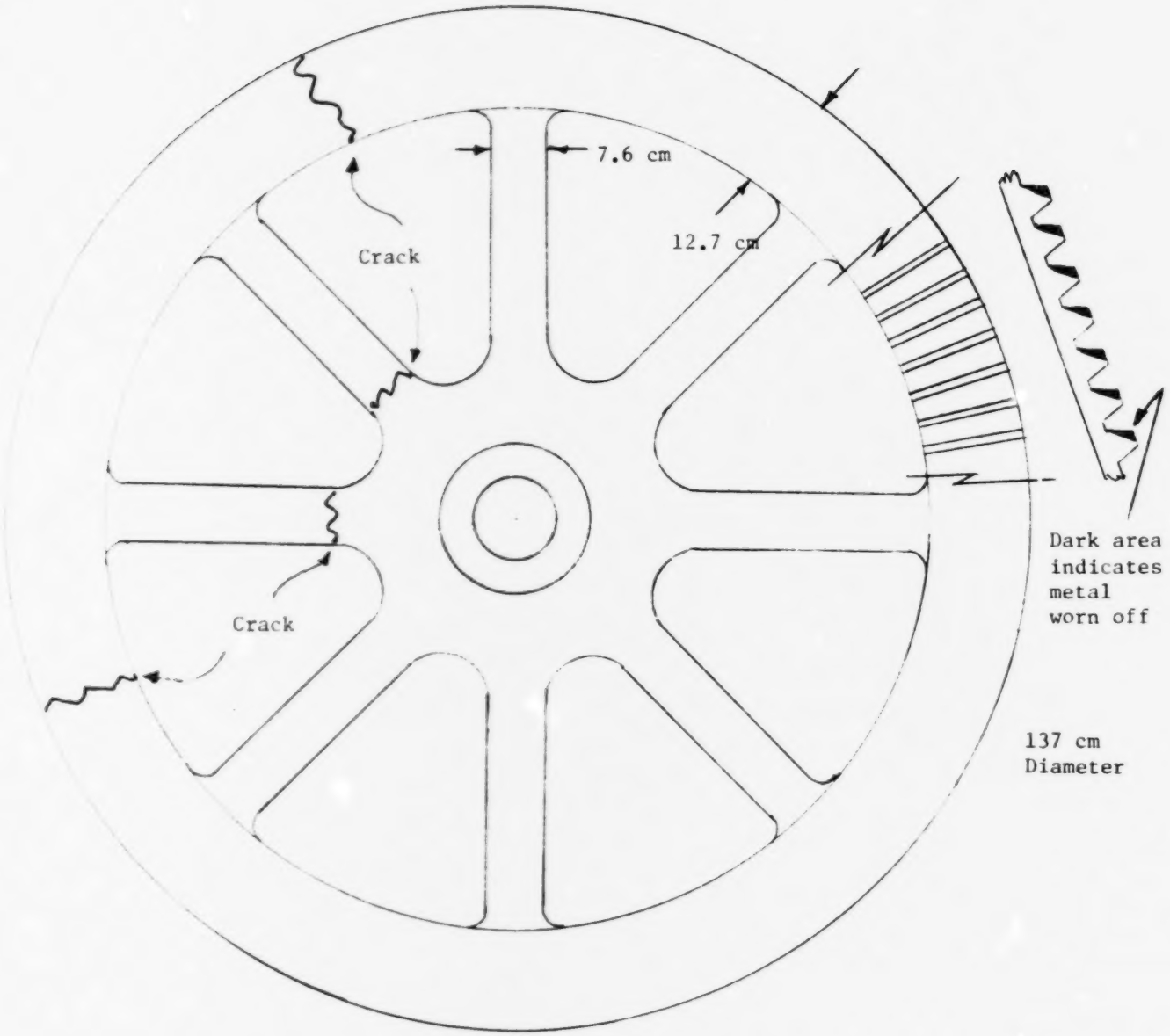


FIGURE 51: Classifier Drive Gear Showing the Location of the Fracture Through the Outer Drive Ring and Two Spokes, Plus the Wear Profile on the Ninety-Six Teeth

Ni-2 electrodes (2.5 mm diameter) were also used for the buttering layer on the worn faces of the gear teeth. NiFe-2 electrodes (3 mm in diameter) were used for all the remaining layers that were required to build-up the teeth to their original shape.

The drive gear was turned when necessary throughout the repair and build-up to enable all welding to be done in the flat position.

The preheat temperature was maintained on the entire classifier gear between work shifts using electric strip heaters. This procedure maintained the complete gear at uniform temperature at all times and eliminated the need for preheat at the start of each work shift.

4.4.4 Cost Effectiveness of Repair in Comparison to Replacement

The total cost of the weld repair and build-up of the gear teeth that included labour and welding consumables was $6,500. The repairs to the fracture plus build-up took one month to complete on a one welder per shift, one shift per day basis. The fracture had occurred two days prior to the regular seasonal shutdown of the plant. Thus as production was not scheduled to resume for five months additional welders or shifts were not necessary.

A new classifier gear was estimated to cost $10,000 with 6 to 9 months delivery. The major problem was a lack of a pattern or engineering drawings for the part. With this delivery, resumption of production would have been delayed one to four months with a substantial production loss.

The repair welding saved a minimum of $3,500 in comparison to a replacement, plus a potential production loss of 25,000 tons of product per week.

The classifier gear failed a second time after 4 years service through the welds of the first repair during a peak production period. The gear was repaired following a similar welding procedure as was used for the first repair.

The total cost of the second weld repair including welding labour and welding consumables was $3,700. Two welders worked continously for 39 hours to complete the weld repairs. Total production time loss was 55 hours.

Replacement cost estimates varied from $10,000 to $20,000 with deliveries 6 to 9 months. A major problem, as during the first failure, was a lack of pattern or engineering drawings for the part. Extremely high production losses would have resulted if repair welding had not been done.

It is reasonable to assume that a similar, used classifier could have been located, purchased delivered and installed in approximately two months. Assuming this could be done at a cost of $7,000, the repair welding would still have saved approximately $230,000 of lost production.

4.5 Build-up of Stationary Jaw in Primary Jaw Crusher (Quarry)

4.5.1 Technical Function of Failed Part

The stationary jaw of a 107 cm by 102 cm Allis-Chalmers Superior primary jaw crusher used at a quarry, had worn extensively on the crushing face that was in contact with the underside of the wear plate. Figure 52 shows a jaw crusher of the type that is used at the quarry operation.

The jaw crusher consists of two crushing surfaces, one fixed or stationary jaw, the other a movable or swing jaw. The stationary jaw of the crusher at the quarry was an integral part of the 40 ton main frame, made of gray cast iron. The movable jaw pivots on a shaft at the top of the jaw and is oscillated at the bottom by movement of the toggles and pitman that are driven by the eccentric shaft. The product progresses by gravity between the jaws and is crushed by the pressure ex erted by the oscillating action. Figure 36 in section 4.1 shows a cross-section through a jaw crusher of the type used at the quarry.

At some point during service, the bolts that were holding the wear plates to the stationary jaw had worked loose, thus allowing the plates to rub against the face of the stationary jaw.

4.5.2 Description of Failure

Inspection after a high pressure water cleaning operation revealed that the full lower half of the stationary face had worn. The wear area was 102 cm in width and had extended up to a point 92 cm from the bottom of the jaw. The wear depth was 2.5 cm at both edges and bottom tapering to zero in the centre at the top of the wear area. Figure 53 shows the wear profile on the crushing face of the stationary jaw. Magnetic particle inspection of the full crushing face revealed no cracks.

4.5.3 Welding Procedure Used

The welding procedure that was used for the repairs complied to that outlined in the General Welding Procedure Section 3 with the following exceptions and details.

All weld build-up was done in-situ in the horizontal position. Due to the remote location of the quarry, it would not have been economically feasible to dismantle the crusher completely in order to remove the frame for shop repairs. Since the crusher was mounted in an open frame structure, it was necessary to construct an enclosure of wood framing covered with polyethylene sheeting, to protect the frame and welder from the weather.

Prior to welding, the entire surface to be welded was thoroughly cleaned using power wire brushing, then ground where necessary, to produce a clean sound surface for welding.

NiFe-2 electrodes were used for the entire build-up. Electrodes 2.5 mm and 3 mm diameter were used for the buttering layer and 3 mm and 4 mm diameter for the remaining layers. It was necessary to remove the first buttering layer completely because of excessive porosity and poor bonding. The second buttering layer was free of porosity and had bonded well. The weld bead deposition procedure for the build-up was the same as described in the General Procedure for groove fill beads, with the exception of electrode type used.

The preheat temperature of the complete repair area of the stationary jaw was maintained between work shifts, using two large propane torches. At the completion of each work shift the torches were set at a low flame level and positioned approximately one metre from the worn face to prevent localized overheating. This procedure maintained the repair area at a uniform temperature at all times, and eliminated the need for preheat at the start of each work shift.

4.5.4 Cost Effectiveness of Repair in Comparison to Replacment

The total cost of the weld repair, including welding labour and welding consumables, was $5,000. The entire build-up took two weeks to complete on a one shift per day, two welders per shift basis. The repairs were carried out during the yearly, five month winter shut-down.

A quotation indicated that a new crusher would cost $200,000 with a delivery of 12 to 18 months. A new frame would cost $52,000 with a similar delivery. With this delivery, the quarry operation would be shut-down for 7 to 12 months causing an unacceptable production loss up to $3,800,000 plus a substantial milling plant loss.

Another approach was to purchase a used crusher (still underground) from another source for $55,000. However, this would have meant modifications to the existing foundations or building a new one. Both approaches for the foundation work would have been costly.

Thus, the repair welding saved at least $50,000 in comparison to replacement with a used crusher.

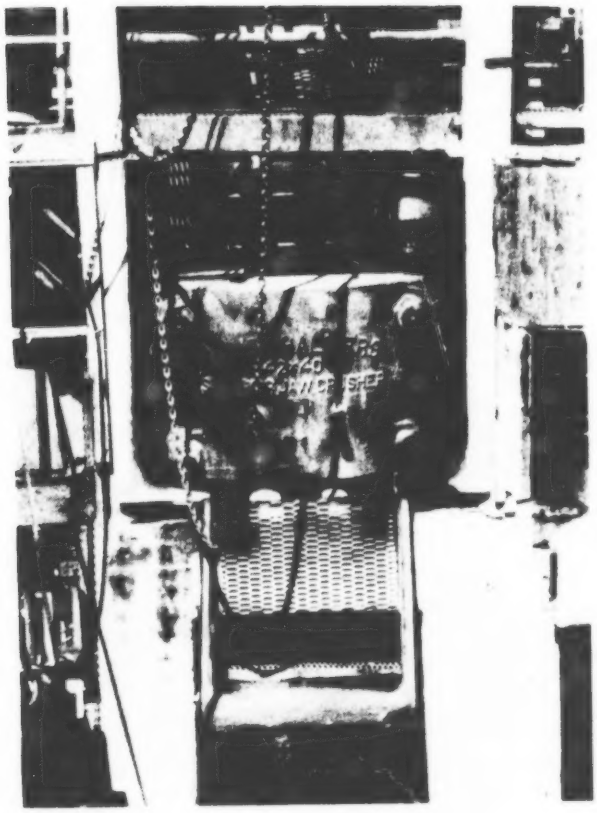


FIGURE 52: Jaw Crusher of the Type Used in the Quarry Operation

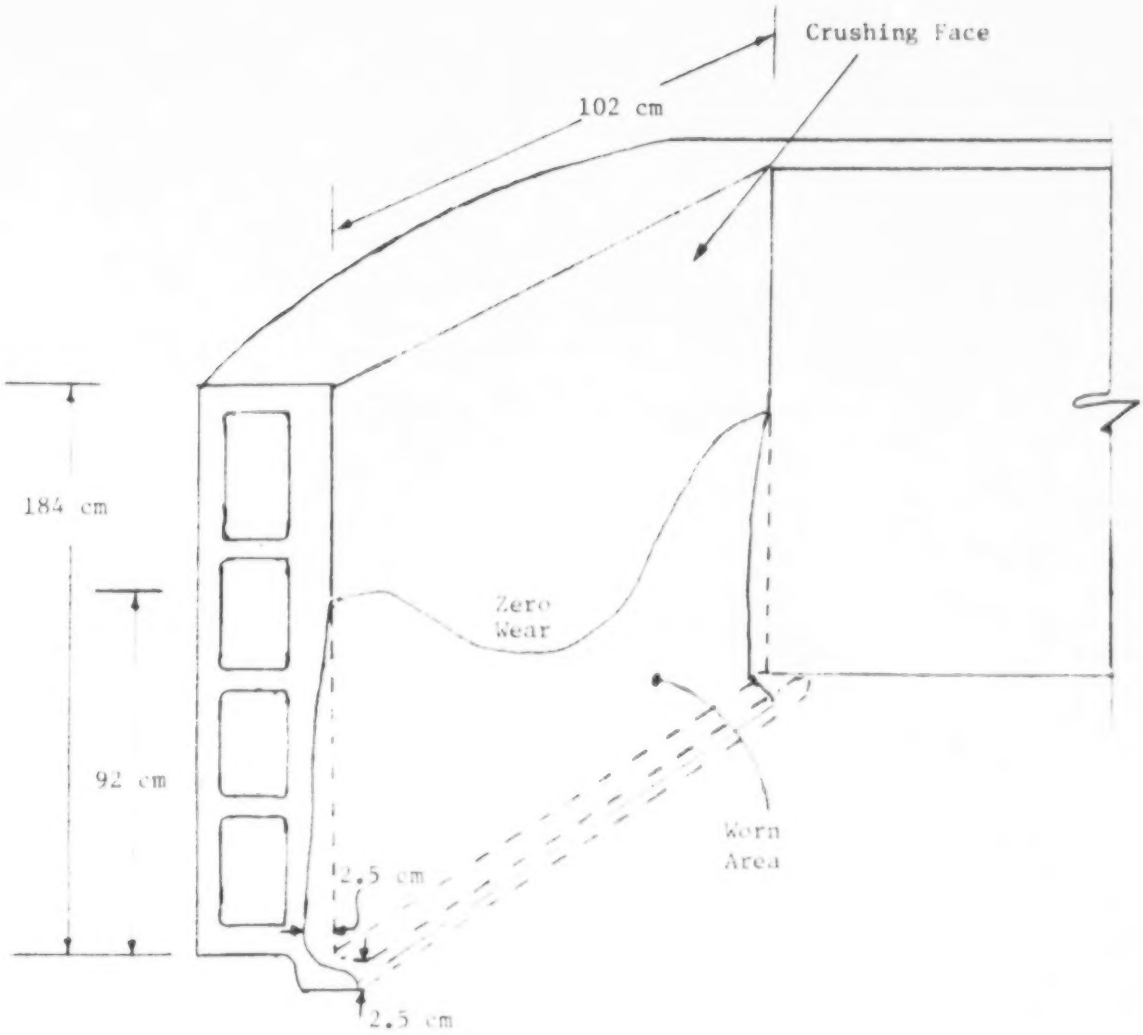


FIGURE 53: Section Through the Main Frame, Showing the Wear Pattern on the Lower Section of the Crushing Face of the Stationary Jaw

5. DISSUSSION

From the prece ding examples it is clear that grey iron castings are widely used in the mining industry. The maintenance of grey iron components is critical for ensuring the flow of materials in mining, milling and smelting flowsheets.

When a failure occurs, maintenance staff may have a number of choices, namely:

(1) Replacement of machinery with a spare which has been purchased and is in stock.

(2) Order new machinery from an original equipment manufacturer (OEM)

(3) Order new components for the existing equipment from a jobbing foundry or OEM.

(4) Order used equipment from another mine or equipment dealer.

(5) Replacement of machinery with equipment from a less critical process circuit.

(6) Diversion of production to an alternate process circuit.

(7) Repair of existing equipment.

The five case studies demonstrate that welding repair can be effective from both a technical and economic perspective. Economically savings were realized in the case studies merely in the cost differential between repair and replacement. However, in the absence of an alternate process circuit, production losses from replacement far outweighed production losses occasioned by repairs, thereby further justifying repair whenever possible. They also indicate a number of areas where the present technology could be improved.

(1) SMAw is slow and labour intensive: semi-automatic welding would reduce the cost of welding labour and lost producton.

(2) The properties of weldments in comparison to castings needs to be defined more closely, so better decisions could be made for repair of highly stressed components.

(3) Electrode selection is currently done on a trade name basis. The technical features of superior electrodes needs to be determined.

6. CONCLUSIONS AND RECOMMENDATIONS

(1) Welding repair of grey cast iron mining equipment can be done effectively from both a technical and economic point of view.

(2) Substantial production losses at mining operations can be avoided by repair welding of grey iron components.

(3) There is a need to improve the existing weld repair technology, in terms of welding rate, electrode selection and weldment properties.

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Attach.

S. Shewchuk

R. J. Dawson

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